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ELEMENTS OF FOOD ENGINEERING

Volume Two

UNIT OPERATIONS. 1.

by

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Preface

Since embarking upon the task of preparing "Elements of Food Engineering," we have been confronted with a series of events that have necessitated extensive revision of our original plans.

To begin with, we were seriously handicapped with the untimely passing of Mr. E. S. Stateler. To the many who knew "State," as he was affectionately known to a host of friends and professional associates, it will be readily understandable that his loss was keenly felt for not only was he a fountainhead of knowledge with a marked editorial talent, but, in addition, he shared with Dr. L. V. Burton the original conception and conviction of the need for a profession of food engineering. While we had the considerable benefit of his counsel in formulating the outline of the various chapters, the loss of his editorial contributions were most keenly felt. Fortunately, Mr. G. G. Hawley volunteered his considerable talents and to him we are indebted for his extensive labors in making this and the subsequent volume of a quality consistent with that of Volume 1.

Dr. Ellery H. Harvey, because of illness in his family, was obliged to tender his resignation as Professor of Food Engineering at Illinois Institute of Technology and move to Florida. The absence of his active collaboration was also keenly felt. The presentation of the subject matter in Volumes 2 and 3 was his original idea—and will prove one that will be increasingly appreciated by those who will be teaching the unit operations of food engineering, the need for which is daily becoming more and more urgent. It was Dr. Harvey's premise that the various unit operations should be presented in a unifying and clarifying manner by their systematic grouping into sections according to their incidental functions such as is more completely explained in the Introduction to Volume 2.

Finally, it was discovered that so much textual material was involved for an adequate discussion of the various unit operations that it was necessary to divide it into two volumes so that it might conveniently become the subject matter of appropriate periods for effective pedagogical presentations. Accordingly, it was decided to divide the unit operations textual material with the result that Volume 2 as originally planned has become Volumes 2 and 3.

Again, various companies, individuals and organizations have cooperated splendidly in furnishing photographs and information that have contributed immeasurably to the value of this book. In addition to those acknowledged in the credit lines, the author wishes to express his appreciation to all who have contributed in any and all ways to the preparation of this book. If any omissions have resulted, we hope they will be brought to our attention.

MILTON E. PARKER

Chicago, Illinois
May 1954

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Introduction

The Unit Operations concept of food engineering (as defined in Volume I) primarily concerns the physical means and equipment used to effect the changes in composition or form which characterize processed foods. Thus, all the various operations involved in food processing can be reduced to certain basic operations which have common objectives; the techniques or methods involved may vary in detail, but not in principle. Consequently, a professionally trained food engineer designs equipment bearing in mind the particular unit operation or operations to be performed; by so doing he is not distracted by unimportant distinctions. Lack of appreciation of the true significance of unit operations often constitutes a "blind spot" in the analytical thinking of many practical food plant operators, and thus obscures obvious solutions to operating problems.

Thus, while from an academic point of view the unit operations concept is essential in gaining a true understanding of food-engineering principles, it should be recognized for what it truly represents: namely, an engineering and analytical basis for collecting, correlating, and classifying related physical means for performing basic operational techniques or unit processes. These embrance all the presently known methods of cleaning, coating, controlling, decorating, disintegrating, drying, evaporating, forming, heat exchanging, materials handling, mixing, packaging, pumping, and separating in the industrial processing of foods. Their exposition and discussion will provide the text for this and the subsequent volume.

Although the unit operations concept provides for an engineering approach in studying food-processing problems, it is obviously impossible to have standardized plans for the design, construction, and operation of all the various types of plants and equipment. The equipment must be modified to accomplish results peculiar to a given division of the food-processing industry. It is sometimes possible to use standardized units in large variable production systems and occasionally in food-processing applications not envisioned in their original development. However, ideal as such adaptability might be, there are invariably complications in integrated production wherein the problem is one of choosing the best available units designed to operate with the appropriate speed. This is rather obvious, inasmuch as the production capacity of one machine is not necessarily the same as that of another whose operations have to be synchronized in an orderly, economically operated food-processing line.

It should also be emphasized at this point that most food-processing equipment invariably performs more than one unit operation. In fact, it is difficult to design equipment that normally does not perform at least two or more unit operations simultaneously. It is this common experience that confuses many individuals not accustomed to thinking in terms of engineering principles.

The kind, amount, and arrangement of plant equipment depends upon the nature of the food to be processed. Due consideration must always be given to the economic factors involved. For instance, not only is the pea-packing season short, but so much special equipment is required that the plant is usually not suitable for other items. On the other hand, carrots and beets require only the relatively simple equipment found in every canning plant using retorts for thermal processing or pressure cooking.

In spite of the great diversity of design made necessary by the wide variety of products and synchronization of production, there are certain qualities which every adequate food machine must have:

(1) It must do economically the work for which it is designed
(2) It must be as simple in design as good engineering practice permits
(3) It must be sturdy in construction
(4) Its materials must be noncorrosive as well as noncontaminating
(5) It must be easily disassembled and reassembled for sanitary and operational control

These prerequisites are of importance both to the food engineer whose responsibility is primarily equipment design and to the person charged with plant operation and production management.

For the purpose of unifying, as well as clarifying, the text of this and the subsequent volume, the various unit operations have been grouped into sections according to their incidental functions:

Section 1—Assembly of Raw Materials
Section 2—Preparation of Raw Materials
Section 3—Conversion of Raw Materials
Section 4—Treatment of Finished Products

Admittedly, the classification is a loose one. There are instances where a unit operation appears in several sections but always for rather obvious reasons. There are also instances where the serious student may feel a given unit operation might just as properly be considered in another category. With such opinion, the author has no quarrel. Food engineering is the youngest of the engineering professions. Therefore, the most anyone can do at this stage of development is to enunciate principles, not make a sdemic pronouncements nor indulge in profound semantics or even editorial qualms.

It will be apparent to the student of food engineering that the industrial production, preparation, processing, handling, and distribution of foods employ methods common to a variety of food products. With his increasing knowledge, he will also be impressed with the necessity of combining care and speed in the implementation of various unit operations because of the inherent perishable nature of most foods. The primary objective of all industrial food operations is the conservation or preservation of foods in such a way that the ultimate consumer will be assured of optimum quality at minimum cost. Therefore, the proper selection of raw materials, their careful handling and judicious processing, their proper packaging and effective distribution, must all be encompassed within the practicing of food engineering, to insure consistent and controlled quality. Thus, in studying the essential elements involved in the unit operations employed in industrial food production, it will be helpful to first outline the causes of food deterioration and loss. In other words, a systematic appraisal of food spoilage will reveal the underlying biological, chemical, and physical principles upon which all methods of food preservation must be based.

CAUSES OF FOOD LOSS AND SPOILAGE

While we shall attempt to classify only the more important causes of the spoilage, deterioration, and loss of foods, it should be kept in mind that many act in various combinations, although each alone may ultimately destroy the foods whose quality they first impair. They are:

(1) Animal pilferage
(2) Insect infestations
(3) Microbiological infections
(4) Enzymic actions
(5) Chemical factors
(6) Physical agencies
(7) Contaminating effects

Animal Pilferage

Among the higher forms of animal life destructive to foods, we must include mammals and birds. Birds play a very minor role, to be sure, but they can become a nuisance if they are not subjected to ordinary control measures. Water tanks seem to be attractive to birds as a shelter but if proper defense methods are taken to prevent their ingress, they present no serious control problem. Stored grain also attracts birds, as they prefer to feast upon such stores than to forage for themselves. Sometimes they do great damage to growing crops, but protective measures are relatively simple.

Cats and dogs can be sources of annoyance, but the greatest enemies to food processors are rodents—particularly rats. They destroy plants, textiles, and merchandise, eat fruits, vegetables, cereals, meats, and other foods, and pollute many times as much as they eat; they may cause fires by gnawing on matches or into electric lines; they gnaw woodwork and even the softer metal pipes as well as undermine pavements and floors. In short, they are by far the worst of animal pests.

Rats are probably decreasing in numbers in some parts of the United States, although their decrease is only beginning to be apparent. The chief factors responsible for this trend are (1) present-day sanitary requirements and modern building construction, which make food and shelter increasingly difficult for rats to find, (2) a better general understanding of their relation to human economy, and (3) a national campaign against unsanitary habits and practices in food-processing and food-handling establishments.

Whenever rats infest a food plant, it is practically certain that hairs and excrement will be found in the finished product. The spread of disease by such filth is an ever-present threat. The Food and Drug Administration has had many indictments against food-processing plants in the past for the presence of rat hair and excrement in their products, or merely for the evidence of an abundant rodent infestation inside the plant premises. This close policing by governmental agencies is certain to become even more stringent in the future.

Mice in food plants are usually of the species classed as the house mouse. In comparison with their size to that of the rat, they cause relatively as much damage, although normally they are not so great a health hazard.

Insect Infestations

The control of insect infestations in food-processing plants presents a constant sanitary problem. A considerable number of species of insects are encountered in various types of food-processing and food-warehousing establishments. The proper use of insecticides depends upon a knowledge of the insects, materials, and methods used. There is a considerable difference in the susceptibility of insects to various insecticides, yet the use of the appropriate materials suitably coordinated in the chemical control of insects, combined with proper operational practices, can keep a plant practically free of infestation the year round. It is important to know the life cycle, structure, food preferences, and, in general, the favorable and unfavorable conditions for development of the various insects involved. It is equally important to have some knowledge of how insects get into food processing plants because this varies somewhat with the species. When infestation is introduced through raw materials brought into food plants, control must be effected either by rejection or by fumigation.

Insects not only attack natural foods but also adapt themselves to live upon processed foods. Fresh meats can be a breeding place for flies although this condition seldom is allowed to develop. Salted and smoked meats are sometimes infected by larva and worms, and trichina, or small flesh worms, cause a disease in swime which can be transferred to people eating insufficiently cooked pork. Breakfast foods are attacked by the same weevils that infest grains, as are also crackers and cakes. Pepper, paprika, and cocoa can be infested with worms and larvae of various kinds.

Great economic loss in livestock originates in cattle grub infestation which, of course, is not an aspect of materials handling. However, it should be mentioned in passing that such infestations result in annual losses of an estimated 12,000,000 pounds of beef in trimming the cysts from loin cuts as well as decreased values for hides and reduced production of meat and milk.

Microbiological Infections

Pest control problems in food industries actually involve a great variety of animal and plant forms of life. Although insects and rodents usually receive primary attention, microorganisms can prove equally as troublesome, if not more so. Normally, microbiological infections involve bacteria, yeasts, and molds, yet fungi such as blotches, rots, rusts, smuts, and mildews can constitute a problem. In fact, practically all forms of microorganisms are injurious to the quality of different foods either in processed or raw material form and consequently demand the attention of food engineers, technologists, and biologists just as the macroscopic pests are the concern of entomologists and sanitarians.

Two general classes of microorganisms are involved: the pathogenic types, which can cause serious epidemics of typhoid fever, cholera, dysentery, and other infectious diseases; and the saprophytic types that can destroy some of the nutrients in food products or impair flavor, odor, appearance, and other general characteristics to such a degree that they manifest themselves subconsciously by reducing the appetite of the consumer or consciously by being rejected by the consumer because of off-flavor or some other form of inferior palatability or acceptability.

In addition, microorganisms involved in food spoilage may be spore-forming or nonspore-forming, thermophilic or mesophilic, aerobic or anaerobic, oxidizing or reducing, acid- or alkali-forming, putrefactive, lipolytic, hydrolytic, or even cellulose-digestive. Their food-spoilage characteristics constitute the most common and troublesome problems in quality control and maintenance. Their involvement in packaging techniques and materials defies adequate cataloguing. A few examples will point their omnipresence. The premature application of a cold cap to a jar of hot chocolate sirup was reported by Oser[1] as resulting in the condensation of water vapor and consequent dilution of the upper layers of the sirup, giving rise to superficial mold growth. The author experienced the development of cheesy surface taints in creamery butter traceable to its contamination with putrefactive bacteria trapped in the paraffin coating of wet-waxed folding cartons that had been treated with infected water used by the carton manufacturer to obtain a high gloss. Pinhole openings in the Archimedean screw and header of continuous butter cutters have contaminated the product by actually inoculating the butter with the infected water that was used as a tempering medium within the hollowed recesses of the screw and header. A hypodermic needle could not have performed more effectively in injecting putrefactive and lipolytic bacteria into the butter. Ventilating fans have been known to be troublesome by blowing mold spores and other quality-impairing microorganisms around packaging departments. These examples illustrate how packaging techniques and materials can, and often do, contribute to food spoilage.

Microbiological spoilage is a function of chemical composition, moisture content, temperature, and reaction (pH). Purified sugars and starches are never adversely affected by microorganisms as long as they are dry. Fats and oils are virtually immune from damage when purified and free of moisture. Bakery and confectionery products are occasionally troubled with yeasts and molds but are comparatively free from spoilage by bacteria because of their high sugar content and comparative freedom from moisture. Nonalcoholic beverages can be spoiled by yeasts but are seldom attacked by molds and rarely by bacteria owing to the exclusion of air from the containers. Distilled liquors are entirely free from infection by microorganisms because of their high alcohol content, although fermented drinks such as beer, ale, wines, etc., may become infected by certain specialized forms of microbiological agents able to exist in their lower concentrations of alcohol. One of the more common of these forms of life is *Mycoderma aceti*, or "mother of vinegar"—a surface-growing microorganism that has the ability to convert alcohol into acetic acid. Beer is sometimes clouded by microorganisms although this can be the result of chemical decomposition.

Water is essential to all forms of life and, accordingly, a reduction of the amount of water, or moisture, in a food product immediately influences the number and variety of microorganisms that can exist and perform their metabolic processes. The degree of hydrogen ion concentration (pH) also has a great deal to do with the resistance of a food to the attacks of microorganisms. Yeasts and molds grow readily on strongly acid fruits while the heat-resistance bacteria can tolerate a little acid but do grow profusely in neutral vegetables like asparagus, spinach, etc. Minor differences in chemical composition of foods are relatively unimportant in comparison with their moisture contents and reactions.

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[1] Oser, *Food Industries*, **18**, 1683 (1946).

More and more food products are being examined critically for bacteria and other miroorganisms by various regulatory agencies, and as a result, criteria have been set for more rigid specifications and controls in food processing. In many food products, high bacteria counts are accepted as substantial evidence of a lack of proper sanitation, and such indices are being utilized by health authorities for an increasing variety of processed foods. Thus, it is becoming extremely important for many food industries to pay particular attention to bacterial counts in their final products.

From the processor's point of view, the control of microorganisms is, in addition to being a public-health problem and a quality-appraisal method, a matter of economics. If the processor fails to maintain a sufficiently low number of microorganisms in his products, he may be faced with a high percentage of rejections that will reduce his income. Also, microbiological spoilage of the product can reduce yield or increase the burden of returned merchandise, and thus increase the overhead costs on the entire unit of production. The greatest danger, however, aside from the possibility of endangering public health, is that microbiological spoilage of a particular product may ruin the good-will and reputation of a brand and, even more important, turn the buying public away to competitive brands or even to competitive products. For example, poor quality frozen foods will encourage the consumption and sale of good quality canned foods.

Enzymic Actions

While microorganisms are the source of most food spoilage, other biological agencies, such as enzymes, are involved. Enzymic actions are, of course, all functions of living organisms. While enzymes are the products of living organisms, their action is not necessarily destroyed by killing the organisms which produced them. If their activity is not arrested, they can cause many quality defects in food and, if left free to act, can produce a eventual condition of autolysis.

The activity of enzymes is influenced by the same factors and in about the same way as for microorganisms. They have an optimum temperature as well as inactivation and thermal death points. Like microorganisms, they are influenced by reaction (pH) and other factors of the chemical environment. Each may have its own optimum pH reaction and pH range in which it can be active. Chemical substances may retard or enhance their activity depending upon the concentration and specific character of both the chemicals and the enzymes involved. Certain chemicals may inhibit, while others may stimulate, enzyme action. Moisture content also has its influence as, for example, in the case of some dehydrated foods. The moisture content may be low enough to inhibit the action of microorganisms yet permit enzymes to act. These characteristics of enzymes have given rise to the practice of blanching many food products before their subsequent processing in dehydration and freezing, for example. Blanching consists of heating the products in hot water or steam for the purpose of destroying the enzymes, preferably at a temperature low enough not to harm the product's acceptability. Generally, blanching does not destroy all of the enzymes although it does destroy enough of them to give the final processed product an improved keeping quality with an appreciable delay in its loss of acceptability. Similarly, blanching does not destroy all the microorganisms and the enzymes which they contain. However, upon proper blanching, the biological agents that are not destroyed are apparently inactivated sufficiently to permit the optimum processing of the incidental food products.

Normally, heating food products to temperatures of 165 to 170°F for 10 minutes in the presence of water or low-pressure (wet) steam suffices. Some foods can be subjected to less rigorous time and temperature blanching factors whereas others occasionally require either high temperatures, or longer exposure time periods, or both. In the dairy industry, for example, the fact that the enzyme phosphatase is consistently inactivated by those time and temperature factors necessary for complete pasteurization of raw fluid milk has made it possible to determine the completeness of pasteurization of market-milk samples by testing the degree to which the enzyme phosphatase is still present.

Chemical Factors of Food Spoilage

Before the discovery of microorganisms and the action of enzymes was fully appreciated, the spoilage of food was considered in terms of physical and chemical agencies. We realize now that most of the changes that take place in processed foods are essentially those involving biochemical phenomena.

As stated before, microorganisms are responsible for most cases of food spoilage. Not infrequently, however, spoilage may be caused by the action of enzymes in the absence of microbial growth. In a few instances, atmospheric oxidation may be involved. Any of these factors may be acting alone or in combination with the others. However, the spoilage products themselves are generally biochemical in character.

The changes produced by the growth of microorganisms will vary with their types as well as with the composition of the food involved. In foods rich in carbohydrates, bacteria will usually set up fermentations that result in the production of acids such as lactic, of gases such as carbon dioxide and hydrogen, and of alcohols and other compounds. If the initial concentration of sugar is low enough, the bacteria may decompose the food involved to produce carbon dioxide, hydrogen, and methane, or mixtures of those gases, as well as liberate ammonia from proteins or amino acids. Carbohydrates other than sugars may be attacked by microorganisms to produce diastase, for example, which will hydrolyze the starch as the first step in a series of decomposition products.

Bacterial decomposition of protein, however, causes more undesirable changes in foods than the breakdown of carbohydrates. The changes involved are more complex and the end products more varied. The early stages of proteolysis involve the splitting of proteins into polypeptides, peptones, and amino acids. In attacking an amino acid, microorganisms may split off an amino group and liberate organic acids, alcohols, or hydrocarbons. Some of these may yield still other products including simple acids, alcohols, and gases such as hydrogen and carbon dioxide.

The decomposition of proteins is usually associated with the liberation of ammonia and of odoriferous compounds such as hydrogen sulfide, mercaptans, indole, skatole, putrescine, and cadaverine.

Fats are less susceptible of microbial decomposition than are the carbohydrates although extensive changes can be brought about in them. Lipolytic enzymes hydrolyze the fats to produce free fatty acids and glycerol, which may then be fermented in the same way as carbohydrates. It is well to point out that the breakdown of fats may or may not be regarded as spoilage depending upon the character of the food and the food habits of its consumers. The same statement can be made with reference to the decomposition products of carbohydrates. For example, lactic acid in fermented milks, acetic acid in vinegar, and the split fats in cheeses are all acceptable in such products, largely because they are controlled to give intentional characteristic flavors. When present in foods in which they are not normally contained, thereby causing unintentional flavors, they are considered spoilage end products, and render the food unacceptable.

Fats may also undergo rancidification because of microbial action involving a breakdown of the fatty acid portion of the fat with the formation of shorter-chained acids, aldehydes, ketones, and peroxides. Concurrently, there occur changes in odor and taste that make the food undesirable.

Oxidative changes associated with food spoilage nearly always are concerned with the oxidation of fats although other oxidative changes are sometimes involved. Undesirable changes in flavor and color are sometimes induced by oxidations not associated with fats alone. In the United States foods in which the fats are rancid are considered spoiled and not only is the flavor adversely affected but certain vitamins are destroyed. Even toxic compounds are developed from some of the by-products of oxidized fat.

Oxidation is probably the most important of the chemical factors affecting foods and is particularly damaging to those containing high concentrations of fats and oils. It also is detrimental to the quality of foods containing essential oils.

Physical Agencies of Food Spoilage

Among the physical agencies of food spoilage is radiation, which may be visible, ultraviolet, or infrared. Light, or visible radiation, may cause discoloration, adverse nutritive effects, or undesirable flavor changes. Beer can be rendered "flat" in taste and milk can develop tallowy flavors and lose much of its riboflavin content by exposure to sunlight for even a few hours. Ultraviolet radiations can induce oxidative types of spoilage. Infrared radiations can produce dehydration, loss of volatile flavors, alteration of protein, or changes in weight, volume, texture, and general appearance through any excessive heat that it might generate within a food product. Crushing, pressing, and bruising frequently make fruits and vegetables unsalable or result in the loss of nutrients because of expression of liquids or the reduction of vitaminic potency catalyzed by the enzymes liberated upon cellular destruction.

Uncontrolled freezing of foods due to unexpected climatic conditions is another common cause of food spoilage. Dehydration likewise contributes to food spoilage through loss of moisture or other factors. Mechanical spoilage of food results from carelessness or through the use of poor equipment and materials, or the introduction of foreign particles such as metals, glass, rust, and dirt. Almost every cause of spoilage in foods is accelerated by the presence of natural water, which usually gets into food through inadequate packaging protection or carelessness in handling. Indeed, use of the proper physical barriers in package construction must be assured, as the absence of the complete protection can prove conducive to food spoilage. Many foods can have their quality impaired by water vapor, for example, even though they may actually be protected from exposure to water itself.

Contaminating Effects Contributing to Food Spoilage

In the foregoing discussions of the causes of food spoilage, we have mentioned instances where destruction of food was accompanied by macrocontamination as distinguished from microcontamination in which latter case trace metals are usually involved. It is obvious that foods may become accidentally contaminated with almost every kind of known matter, both injurious and noninjurious. However, as our food supplies are handled more and more in large factories, packaged in metal containers and other materials, the problems of metallic and foreign particle contaminations have tended to increase. More recently the casual contamination with pesticides has given concern to such groups as the American Medical Association and the U. S. Food and Drug Administration.

Whatever the metal used in constructing food-processing equipment, due consideration must be taken of its contaminating possibilities. Copper and iron must be avoided in the dairy industry as only a few parts per million of either metal in milk will adversely affect its flavor. Zinc, lead, cadmium, and antimony should never be used as a food-contact surface because definite toxic effects from foods contaminated with traces of these metals can result. Babbitt metal for soldering should never contain more than 10 per cent lead. Tin is a much better metal to use for plating a food-contact surface than any of the metals mentioned above. Cadmium is prohibited by most public-health regulations. The judicious use of metals in the construction of food-processing equipment is essential, as galvanic corrosion due to wet contact of dissimilar metals can take place in a food product, the food acting as an electrolyte.

The metallic salts formed by the reaction between food products, or their ingredients, and metals are capable of damaging food products in several ways. Many of the salts themselves have a pronounced metallic, astringent, or bitter taste. Their mere presence, even in trace amounts, will impart metallic or other off-flavors, or otherwise adversely affect palatability. The salts of some metals are active oxidizers and catalyzers, and their presence tends to incite complex chemical changes in many food products. Furthermore, the flavor-damaging reaction of some metals may involve a selective influence on bacteria, accelerating certain objectionable forms of microbiological life. Metals that are oxidizers (copper, iron, nickel) are destructive also to certain vitamins, especially those of the vitamin C group.

High among the list of acceptable metals for food processing are the stainless steels, particularly the alloy commonly used in dairy equipment containing 18 per cent chromium, 8 per cent nickel, and the balance low-carbon steel. The high resistance of stainless steel to atmospheric corrosion is due to its protective coating of a continuous, self-perpetuating chromium oxide film. Chrome-nickel alloy, of which "Inconel" is a representative, containing approximately 13 per cent chromium, 80 per cent nickel, and 6 per cent iron, has been found equally as resistant to corrosion as the 18-8 stainless steels. It has the added advantage of superior ductility, lending itself better than stainless steel to the fabrication of helical coils in vats, vacuum pans, etc. Other metals and alloys are also acceptable, but most of them lack the over-all advantages of stainless steels and similar alloys. The application and advantage of various metals in equipment construction for specific food industries will be discussed in subsequent chapters.

Metallic contamination has required careful attention and study because canned foods may acquire small amounts of iron and tin from contact with their containers. The tin coating on the tin plate from which a sanitary can is made cannot be made absolutely continuous. Under the microscope, minute areas are observed where the steel base is exposed. Foods packed in plain (unenameled) cans are, therefore, exposed to both iron and tin surfaces. The amounts of these metallic salts thus acquired will depend, in part, upon the character of the food—acid foods tending to take up more of these metals, especially when air is admitted after the can is opened. Food packed in enameled cans may also have limited contacts with iron and tin surfaces because of minute abrasions in the enamel coating unavoidably introduced during fabrication of the can after the flat sheet is coated.

Metallic contamination of canned foods was a considerable problem in the earlier years of the commercial expansion of the industry. Swelling or perforation of the cans, particularly those containing corrosive products, notably the common fruits and acid products such as sauerkraut and pickles, created so much difficulty that the packing of such products 30 years ago was considered a highly hazardous undertaking from an economic standpoint. Many hypotheses developed concerning the causes of these defects, and it was ultimately established that they were due to the amounts of silicon and phosphorous in the tin plate used. With the development of a highly corrosion-resistant type of tin plate, it became possible to pack fruits and other corrosive products safely. Another acute problem, associated with metallic contamination, was that of discoloration of certain products packed in plain tin cans. Some highly pigmented fruits and vegetables appear to bleach out and lose color on contact with tin. Sulfur-bearing products—notably corn—developed a black discoloration of iron sulfide which was unsightly and influenced consumer acceptance. This problem was solved through the development of enamels. Today, can enameling is highly specialized, and research to develop linings suitable for various types of foods is constantly being conducted.

Although it is true that no serious cases of contamination of food stuffs by lead or arsenic have arisen, some food manufacturers have their own specifications for the amount of lead and arsenic in wrappers used for their products. One manufacturer, for example, requires that the wrappers shall contain less than 0.1 grain of lead per square foot. Another firm has the following requirements:

Wrapping Paper:
  Arsenic—not exceeding 10 ppm, as arsenious oxide
  Lead—not exceeding 50 ppm
Tin and Aluminum Foil:
  Arsenic—not exceeding 0.4 grain (57 ppm) as arsenious oxide
  Lead—not exceeding 20 grains per pound (286 ppm)

Aluminum-Coated Paper:
Arsenic—not exceeding 50 ppm, as arsenious oxide
Lead—not exceeding 300 ppm
Printed Wax Paper:
Arsenic—not exceeding 50 ppm, as arsenious oxide

When made from new pulp, white paper itself is unlikely to contain more than minute traces of either arsenic or lead, but when waste materials are used the risk is greater. Waste paper, however, may have been printed with lead pigments and thus confer on any new paper a high lead or arsenic content although it is not likely to be so high as to cause trouble. Because of this and other possibilities of contamination, there has been a definite trend to require paper made from virgin stock particularly when intended for use in the fabrication of fiber containers for liquid food products such as milk.

THE INFLUENCE OF FLAVOR

From the foregoing discussions of the various general causes of food spoilage, we can more readily appreciate the many biological, chemical and physical influences which must constantly be guarded against. They serve also to reemphasize the necessity of combining care and speed in the implementation of various unit operations because of the inherent perishable nature of most foods.

Before closing this discussion, it should be pointed out that there is an increasing awareness among food processors of the need to conserve flavors as well as nutrients in foods. Furthermore, one does not have to qualify as an epicure or a gourmet to recognize this trend. Whereas the first phase in the commercialization of food processing was directed at public health aspects in order to win public acceptance, it was subsequently observed that both the refining and sterilization of foods were impairing their natural nutritional qualities. More recently, the effect on flavor acceptability has been impressing the more progressive industrial leaders. The recent introduction of trained taste panels to evaluate foods organoleptically, rather than relying on laboratory tests, is a belated step in the furtherance of flavor acceptabilities of foods. That elusive combination of taste and odor, commonly referred to as flavor, does not lend itself to the precise specifications possible in a chemical analysis, to be sure. However, it does stimulate sensory perceptions that are too subjective to measure. One can recognize a "mouth-watering" steak without being able to describe it!

Modern food processing has contributed greatly to the large scale manufacture of safe as well as tasty foods. It has also made notable progress during recent years in conserving essential nutritive elements. Nevertheless, food should be delicious as well as being safe and nutritious. The alert food processor or packer finds his efforts amply rewarded when he bases his production on consumer preferences as measured by accurately calibrated market surveys. The realization of all these basic characteristics is assured by the contributions of trained food engineers in design, construction, and operation of proper machines, equipment, and processes.

Section 1

Assembly of Raw Materials

14. Materials Handling

The industrial production, preparation, processing, handling and distribution of foods require a series of steps which are primarily physical in character, although their effects may contribute to biological, chemical, and physical changes in the foods themselves. Because of the perishable nature of most foods, the unit operations involved must of necessity combine care with speed.

Care must be exercised to prevent contaminations of various sorts in order to avoid changes in palatability due to subtle alterations in odor, flavor, taste, and possibly texture. Also, physical fractures can contribute to significant losses in nutritional qualities which are affected by a wide variety of biological and chemical factors. Foods do not lend themselves naturally to mass production techniques. Accordingly, to make the time lapse between the receiving of a raw product and the processing, packaging, and distribution of a finished food as short as possible is a fundamental precept of modern food processing.

Actually, the operation of a modern food plant involves primarily the utilization of materials handling systems. Much of our modern harvesting, transporting, and receiving of raw foods is similarly mechanized. The raw material enters the processing plant in divers ways, and, dependent upon its character and uses, is either moved into materials storage, or into immediate processing. Most ingredient materials are usually not perishable, or at least not readily so, and thus can be accumulated for utilizing and dispensing as needed. Natural foods, however, generally require immediate processing, and must therefore move into production promptly. In fact, the materials handling of raw foods reaches back into the production phases of their harvesting, transporting, and receiving so that proper synchronization with processing must be provided in the interests of maximum nutritional values and optimum acceptabilities. Moreover, materials handling is not confined to the gathering, receiving, and processing phases of industrial food manufacture; it is involved in its packaging, storing, and shipping phases as well. Indeed, materials handling contributes largely to the cost of producing food for the tables of the land. As much as 50 per cent of processing time, and costs varying from 10 to 50 per cent of the total manufacturing costs can be traced to its incidental influences, or lack of them. Fragility and perishability are factors that have to be considered in the materials handling of food materials and products. These call for variety in the design, construction, and operation of conveying mechanisms and materials handling equipment. In fact, effective materials handling is essential to orderly and systematic production flow, as well as to economical performance.

In textbooks discussing the unit operations of food engineering, it is not practical to treat exhaustively every food product or the innumerable variations which might be considered. Therefore, no pretense is made of discussing all the materials handling modifications possible in the assembly of raw food materials. However, a conscientious effort has been made to select typical examples. Also, it was decided to treat materials handling from a strictly engineering point of view after the preliminary discussion of its various applications in harvesting, transporting, and receiving operations. Such a method of subject presentation should provide a better comprehension of the engineering principles involved.

It should be emphasized that no amount of engineering skill or "know-how" can ever replace the judicious application of care and speed in the harvesting, transporting, and receiving of raw food materials, nor can it overcome inferior or poor initial quality of raw food materials themselves. Engineering cannot improve the inherent quality of any food, but it can and does enhance food conservation and preservation. In fact, the ultimate objective of all food engineering is to conserve food by assuring its preservation.

HARVESTING

It has been mentioned that materials handling extends back into the production phases of food harvesting, transporting, and receiving so that proper synchronization with processing may be provided. Excellent examples of such essential materials handling can be cited for a wide variety of foods. First of all, the food must be gathered at the proper stage of maturity which is generally when its distinctive flavor characteristics have been attained but before ripening is sufficiently advanced to make it too soft for handling and transporting. Harvesting at the proper stage of maturity is oftentimes an extremely exacting responsibility. The maturing of fruits and vegetables, for example, can be greatly influenced by prevailing temperatures whereas yield can be adversely influenced by harvesting too early and quality impaired by harvesting too late. Considerable experience is usually required in judging the proper time for harvesting. Its estimation can sometimes be aided by intelligent systems of crop schedulings and of field samples in advance of estimated harvest dates. For such purposes use is made of empirical organoleptic inspections or actual tenderness measurements or both. It is normally of decisive importance to handle fruits and vegetables promptly after their harvesting to be assured good quality of processed products.

Fruit Crops

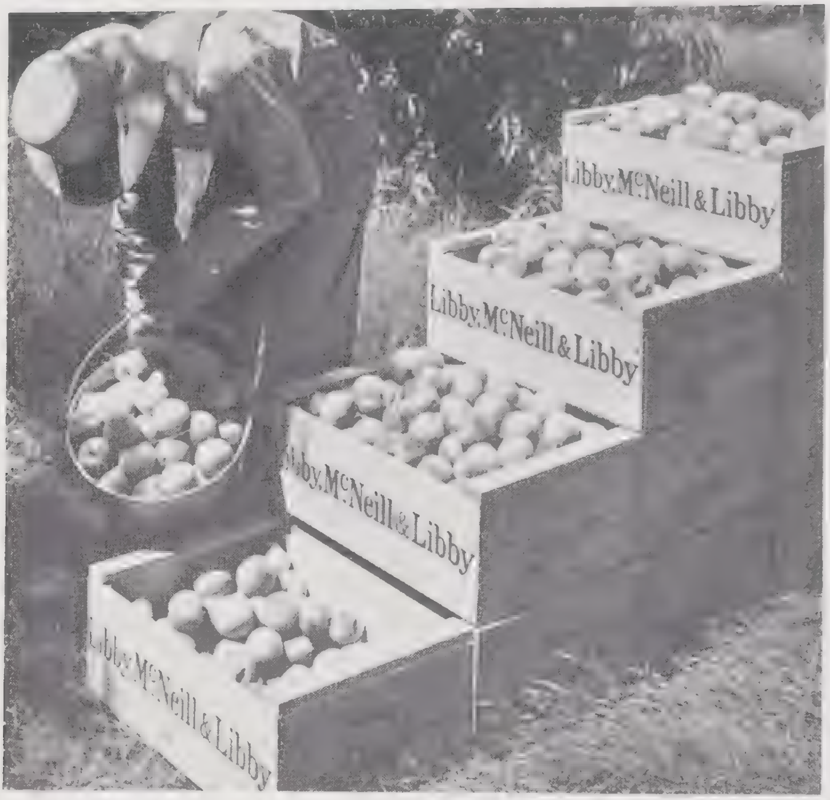
In harvesting peaches, for example, the fruit should be picked when it is in a firm, ripe condition so as to be processed before it softens. Soft peaches are not satisfactory for commercial canning as losses are increased in peeling. Also, soft peaches break up in cooking, the liquor becoming cloudy or the edges frayed, which reduces their commercial value by lowering their grade evaluation. Bruising should be avoided as every bruise becomes a discolored spot which, because of the resultant seepage of saccharine juices, becomes the foci for mold growth.

A good market peach does not necessarily yield a frozen, canned, or glass-packed product of satisfactory quality and appearance. All processed peaches should be packed from the best grade of hand-picked fruit direct from the orchard. Particular care must be exercised in handling the raw product. Lug or field boxes should not be overfilled, and the ends must be cleated to avoid crushing the fruit as well as permit cooling by free exchange of air when the boxes are stacked or loaded into a truck for transporting to the cannery or other food processing plant. Pails, buckets, baskets, or cloth bags are used in gathering the fruit during picking whereas the field boxes are normally used for subsequent transportation of the harvested crops (see Fig. 14.1).

Experience has demonstrated that less spoilage occurs in transit when the fruit is permitted to stand in the orchard overnight to cool. Obviously, in a given orchard, all the fruit does not mature at the same time, making several pickings necessary. If the orchards are in areas maintaining inspectors, sampling can be done on the spot for size and grade.

To avoid deterioration due to overripening, the fruit should be moved and processed promptly. Peaches can be held in storage at 33 to 36°F for several days if necessary. Upon receipt at the plant, the peaches should be placed in a cool, well ventilated room and the boxes segregated according to size and maturity. Any stacking must provide for free passage of air surrounding the fruit.

Apricots, second in popularity only to peaches among California canned fruits, present a special harvesting problem. Optimum maturity for canning lasts but one or two days. If packed green, the canned fruit will have an undesirable astringency which cannot be masked by addition of sugar. If the apricots are picked when too ripe, the fruit will be mushy and unattractive after sterilization. In addition, the syrup will be cloudy because of



Courtesy Libby, McNeill & Libby

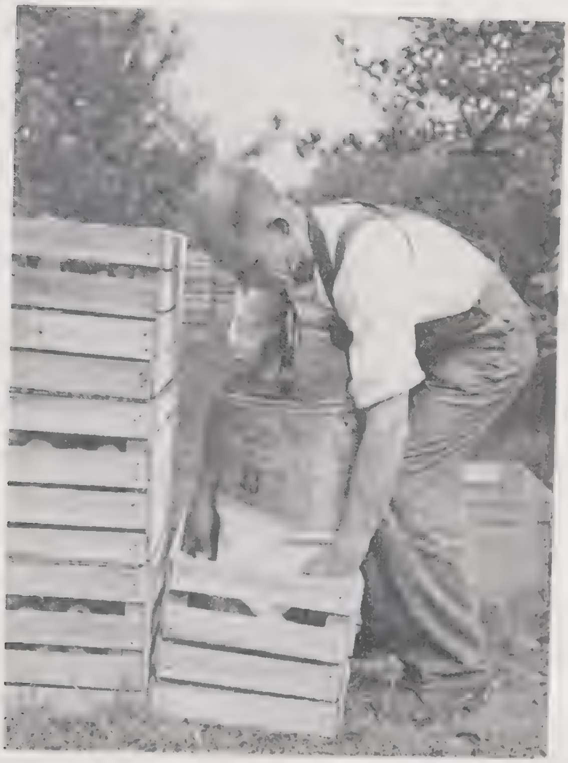
FIG. 14.1. Picker emptying his picking bucket of peaches into lug box by carefully tilting bucket so that peaches roll into box or onto layer of fruit and thus avoid bruising. The filled lug boxes are much too full as stacking other boxes on top will crush or bruise the peaches.

the suspended solids. To obtain satisfactory results, therefore, the apricots must be picked at just the right time and rushed to the plant for immediate processing. Every care must be exercised to avoid bruising.

The demand for apples "as is" is so great that canning of the fruit is regarded as a by-product industry. Apples unfit for canning are converted into sauce, cider vinegar, and pectin. "Wormies" and windfalls are gathered from the ground. The harvesting of top-grade fruit consists of picking from the trees (see Fig. 14.2).

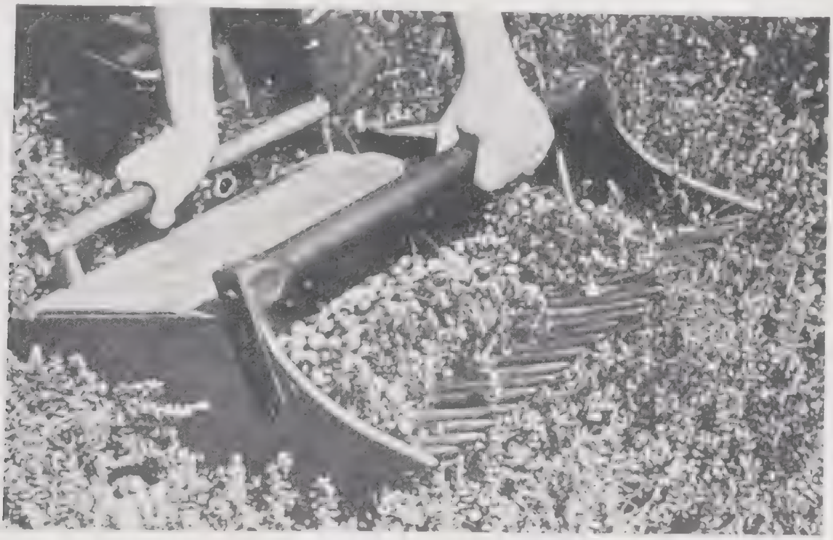
Cranberries are usually picked by stripping the branches of the bushes with wooden prongs cut into the bottom board of a small open-end box called a scoop. The gap between prongs is wide enough to let the branches slip through tearing off the berries, which roll into the back of the enclosed scoop (see Fig. 14.3). Lug boxes, or crates with slatted sides, are used for gathering the harvested cranberries.

Blackberries and raspberries must be harvested in shallow boxes to prevent crushing by packing under their own weight. Picking is done early in



Courtesy Michigan State College

FIG. 14.2. Picker lowering his picking bucket into the bottom of a field crate. This illustrates the approved method. The picker should not stand erect and let the apples drop into the crate as to do so will bruise the fruit. Note the rigid metal picking bucket with canvas bottom.



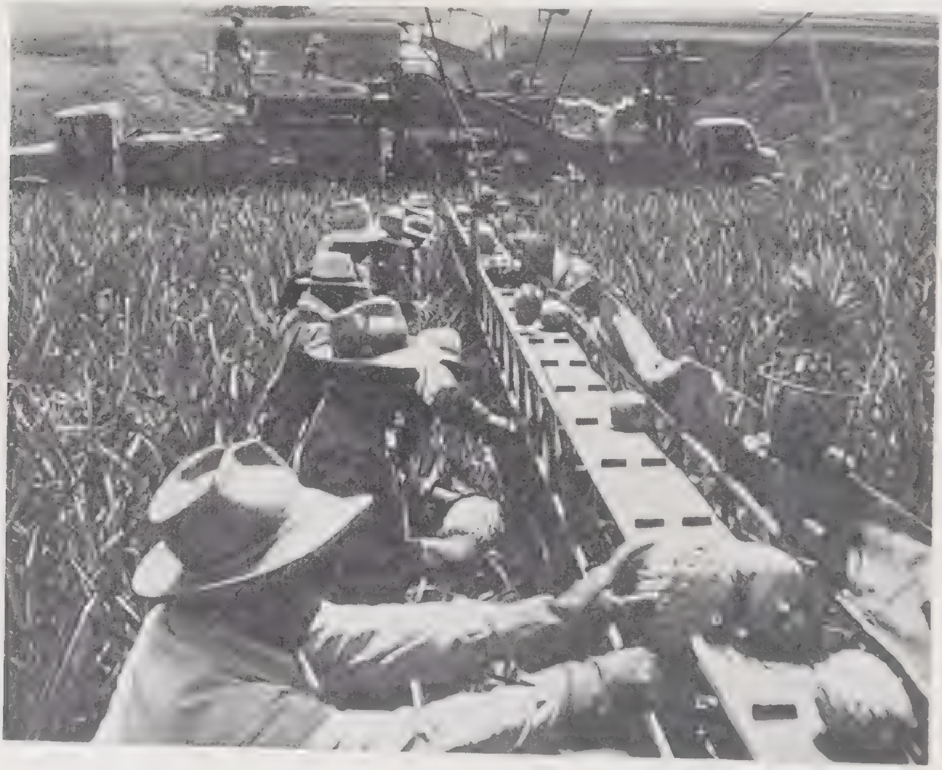
Courtesy National Cranberry Assoc.

FIG. 14.3. Picking cranberries. The vine branches are stripped with wooden prongs; as the branches slip through, the cranberries are torn off and fall into the back of the enclosed box or scoop.

order to get fruit at the proper stage of maturity. The fruit is taken from field to plant immediately and canned the same day. Serious deterioration occurs on standing.

Pears are one of the few fruits which develop a better flavor if ripened in boxes after picking. Tree-ripened pears are coarse in texture. Pears are picked when full size, but green and hard, and shipped to the plant in 50-pound lug boxes where they are held at 70 to 75°F to ripen. This may take up to ten days. Since the fruit ripens unevenly, the pears must be sorted daily. This operation appears to be unique and, to be successful, much good judgment is necessary. If the pears are too immature when picked, they do not ripen properly but shrivel. Such fruit when picked is yellow in color and stringy. When the pears are harvested at a too mature stage they are grainy and too soft near the core.

Pineapples must be allowed to mature fully before picking. Those picked green and allowed to ripen in boxes are lacking in flavor. If picked in an overripe condition, they ferment, and are thus unsuitable for canning. Laborers move between the rows and break the fruit from the plant by giv-



Courtesy Libby, McNeill & Libby

FIG. 14.4 Picking pineapples. Laborers move between rows and break the fruit from the plant with a sharp bend. They twist off the crown before placing the pineapple on the conveyor belt of the harvesting rig which loads the open truck for transportation to the packing plant.

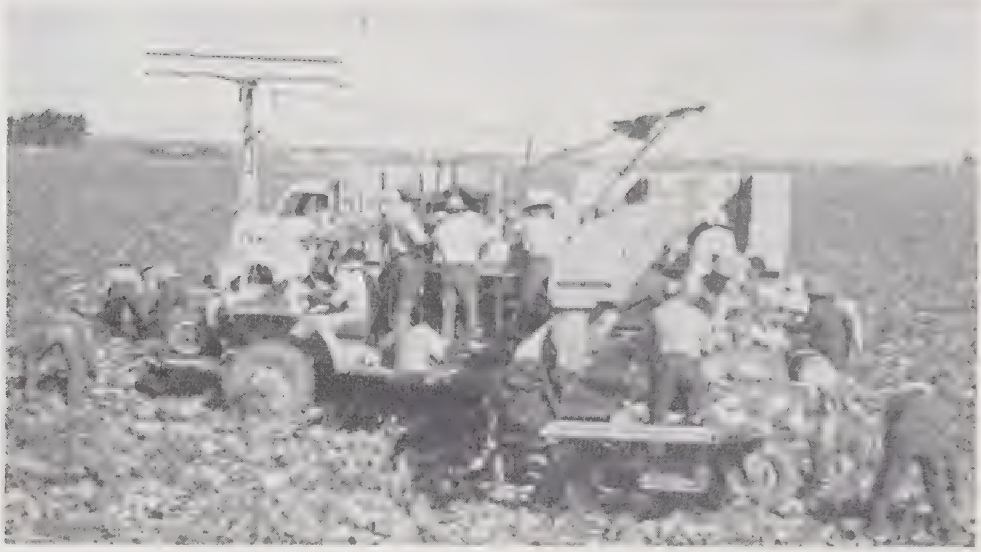
ing it a sharp bend. The pineapples with their crowns torn off are then conveyed to trucks by special rigs and transported to the plant immediately upon completing a load (see Fig. 14.4). Incidentally, the layout of the growing areas is such as to permit the passage of the rigs and trucks at harvesting time.

Vegetable Crops

The vegetable packer, with an eye to profitable performance, has led the grower into raising the varieties most desirable for the particular types of food processing the packer is interested in, such as thermal processing or fast freezing. In many instances, the packer furnishes the seed and fertilizer as well as contracts to buy the growers' crops—all such services being predicated upon obtaining proper quality of raw materials. Vegetables should be uniform in color, tenderness, and quality when harvested, and must be rushed to the processing plant for immediate handling and processing since they deteriorate rapidly after picking. Vegetable packers are so conscious of the need for care and speed that processing plants are usually located in the heart of the crop-producing areas. Certain vegetables, notably sweet corn, tomatoes, spinach, and asparagus, deteriorate with special rapidity. In fact, lettuce and spinach are normally washed and prepackaged immediately following harvesting in order to retain maximum quality for their subsequent distribution. In certain sections of California, for example, the harvesting and prepackaging of spinach and lettuce have assumed gigantic proportions and special refrigerator freight cars, and even airplanes, are utilized to speed such produce to market (see Fig. 14.5).

Many harvesting operations involved in the materials handling of vegetables may be illustrated by peas and beans. Vines must first be cut and windrowed, after which they can be picked manually or automatically with viner combines and loaded into a feeding device. The primary purpose of a viner is to thresh green peas of all varieties, lima beans and other varieties of beans, with a minimum of injury to the shelled product. Of the various method of vining that have been tried, apparently none has proven as satisfactory as the old, original impact principle of threshing.

Peas, for example, should be vined or threshed as soon after cutting as possible. Viners may be located either at the processing plant or at viner stations in the farming areas, from which the shelled peas are transported to the factory in lug boxes or hopper trucks. The viners are usually arranged in groups of one to four units, depending upon the acreage planted in the surrounding territory. Establishing stations away from the plans avoids considerable hauling of bulky unthreshed vines and eliminates the disagreeable odor and waste disposal problem that may arise in the vicinity of a large silage stack. A more recent development is a mechanical pea



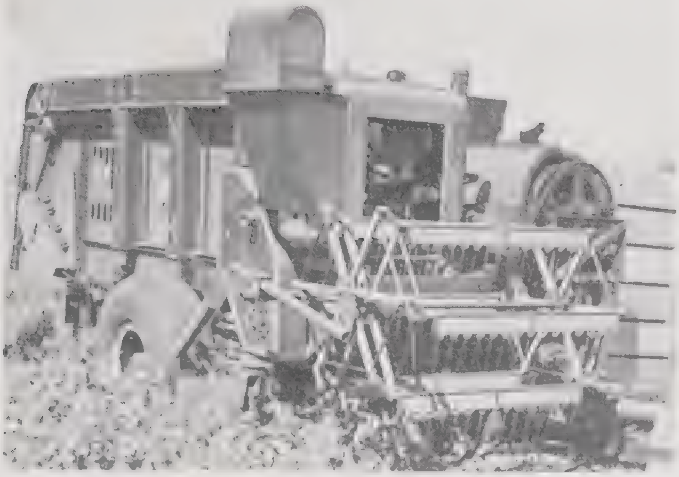
Courtesy F. Hal Higgins

FIG. 14.5. Harvesting lettuce. A crew of field workers harvesting and dry-packing lettuce in Salinas Valley, California. The men on the left are working ahead of the harvester, cutting heads loose, whereas those on the right are following the harvester, picking up the cut heads and placing them on the table. Here other workers are seen packing the harvested lettuce in fiberboard boxes which are carried across by belt conveyor to a transport truck travelling alongside. The dry-packed lettuce is then transported to plants where it is vacuum-cooled prior to loading and shipping for market. This method replaces older iced and crated packing.

harvester that continuously cuts and vines in the field, the shelled peas being collected in lug boxes and the threshed vines deposited on the ground in the wake of the harvester (see Fig. 14.6).

On the other hand, some food processors prefer to locate viners at the plant because vined peas or beans can be handled without delay with quality advantages. The peas should be fed at uniform rate. Nearly all viners are now equipped with self-feeding attachments, which not only make possible uniform feeding but also allow for better adjustment of the rate of feeding according to the condition of the vines. In addition, these self-feeders are labor-saving devices which control the efficiency of the vining operations. For young, tender peas, a speed as low as 160 rpm may sometimes be necessary whereas harder peas will withstand speeds as high as 190 to 210 rpm. These higher speeds thresh the vines more effectively but tend to split the more immature peas. Proper adjustment of the speed may be determined by observing (1) the percentage of peas going into the stacks with the vines and (2) the percentage of splits among the shelled peas.

The threshed vines can either be cured as silage or dried as hay. In Wisconsin and the surrounding areas, the drying of pea vines has not been found to be satisfactory. They are usually stacked or put into silos and then



Courtesy Food Machinery & Chemical Corp.

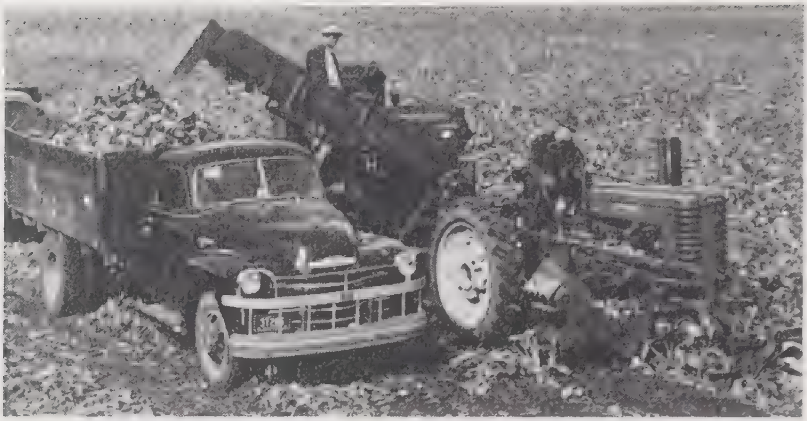
FIG. 14.6. Operational view of mechanical pea harvester taken from feed end that continuously cuts and vines in the field with the shelled peas collected in lug boxes fed by operator whose head is visible over treshing unit.

sold to the growers for use as stock feed. Stacks of pea vines should not be located near streams which feed city or processing plant water supplies because of the possibility of contamination by the fermented liquors draining from such stacked vines.

The threshing of green lima beans for canning or freezing operations presents somewhat different problems than those encountered with peas. After harvesting, the beans must be vined as soon as possible. Green beans are sometimes separated from more mature beans in a gravity salt brine separator. Another method of obtaining such separation consists of operating two viners in tandem. Since the more mature beans are more easily shelled, the first viner is operated at a speed of approximately 130 rpm while the second viner is operated at a somewhat higher speed, such as 180 rpm, to shell the greener beans. While a fair separation is realized by this method, it does increase the vining cost.

Beets and carrots ordinarily are dug out of the ground mechanically. They are then topped, sometimes by hand, but usually by mechanical toppers, which the processing plant provides at the field, although in some instances the beets and carrots are hauled to the food factory and topped there. Harvesters which dig and top the beets and carrots are in general use in some growing sections (see Fig. 14.7).

Potatoes are a crop that is best harvested with mechanical diggers, as experience has demonstrated that such methods provide a minimum of damage due to cuts and bruises. During recent years, potato authorities and leading growers in many sections have considered that more stress

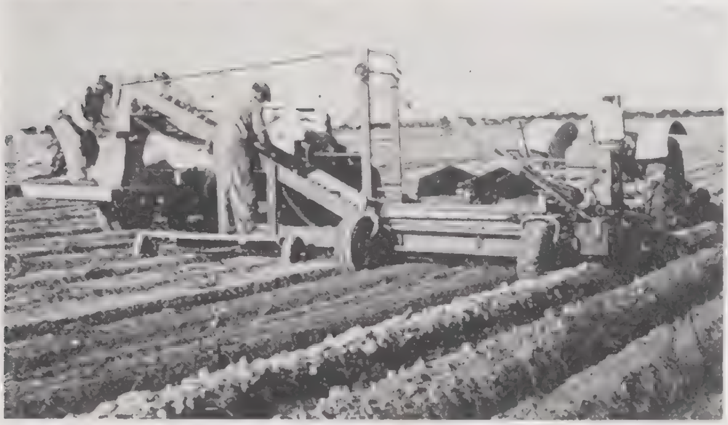


Courtesy Deere & Co.

Fig. 14.7. A two-row beet harvester which tops, lifts, cleans and loads an average of an acre of beets per hour with a maximum crew of four men plus truckers. Notched-tooth device shown on the side of the tractor in the right foreground is a windrowing attachment which can be used to toss four rows of beet tops into a single windrow. An auxiliary engine powers the drawn section of this harvester.

should be placed on gentle handling of the crop at harvest time. Carefully harvested, unbruised crops command the better market prices for potatoes "as is" and also for those subjected to varying degrees of processing. As the proper angle for good digging as well as a low, easy drop from continuous elevators can be provided in mechanical diggers, it is obvious that considerable progress has been made in upgrading the lowly "spud" (see Fig. 14.8).

Corn requires a brief discussion with regard to harvesting. Whole ears of corn harvested when the kernels are in an immature state are used for corn on the cob. When whole ears are to be packed, they are usually selected from the inspection belt where the husked ears are being prepared in the usual manner for other styles of packed corn. They may, however, be harvested specifically for this type of pack. In either case, only corn in prime condition for packing fancy whole grain corn should be selected. Maturity is of prime importance. Since the moisture content is an index of maturity, methods have been developed for such determinations. These include the so-called "thumbnail" test, the Brown-Duvel moisture determination, the succulometer value, and the refractive index of the expressed juice. While these various techniques are used in evaluating corn to be packed as cream style, no single method for determining optimum maturity of corn destined to be packed as whole grain has received industry-wide acceptance. Many standards have been proposed in the latter case, but fieldmen still rely on their own evaluation by the thumbnail test. Ideally, the corn should be young and tender, should have no off-color or malformed kernels, and the ears should be well filled. Corn for a whole grain pack is usually less mature



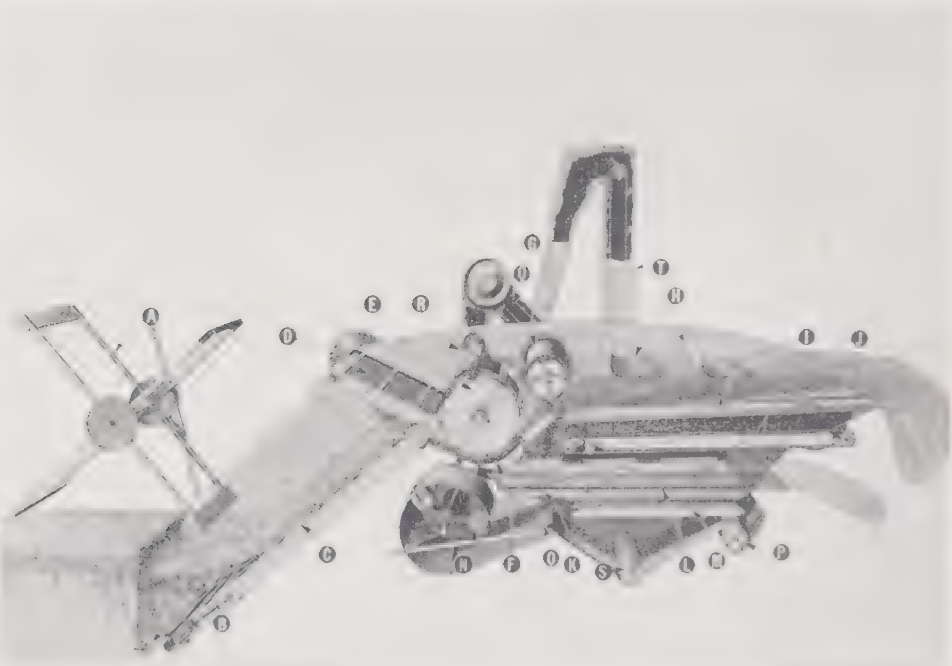
Courtesy Standard Oil Co. of New Jersey

FIG. 14.8. Combination potato digger and loader cuts cost of potato harvest to one-third and completes harvest in one-fourth time necessary by conventional method. This device, built by Henry Weeks of Watermill, Long Island, digs and bags two rows of potatoes at one time.

than corn for a cream style pack. However, it is important to keep in mind that the desirable characteristics of corn can be substantially diminished or lost within a period of three hours if not promptly processed. Picking corn during the coolest part of the day assures a more desirable product, and one less apt to sour before husking. Because of the rapid deterioration of flavor and sweetness, corn should not be stored but rushed to the plant for immediate processing. Plants located at an appreciable distance from the fields are at a serious disadvantage in the production of a top quality sweet corn product. Corn is usually harvested by hand; mechanical pickers have been developed but are not used extensively as yet. Greater uniformity of growing than presently obtains is essential to the success of the mechanical picking of sweet corn.

Many operations involved in the harvesting of vegetables may be illustrated by tomatoes. Tomatoes are grown under diverse soil and climatic conditions in the United States. Many varieties are available. The tomato is one vegetable that does not lend itself to fast freezing processing and, therefore, is canned extensively or processed as soup, purées, or catsup. Tomatoes should be picked when fully ripe but before they start to soften. Tomatoes picked and handled in baskets usually reach the canning factory in better condition than those in crates. Baskets or hampers are recommended because they are lighter, more readily cleaned, allow free circulation of air during shipment, will nest into one another, and will not take up much space when empty. Care has to be exercised, however, to avoid overloading in order to eliminate crushing of the top layer of fruit during the hauling or transporting operations.

In the harvesting of grain and legume crops such as wheat, oats, rye, rice, barley, and soybeans, the cutting, threshing, cleaning, and separating operations are performed in the field with an ingenious mechanical marvel known as the combine. These machines are made with a great degree of adaptability for harvesting crops from the wheat fields of the so-called



Courtesy Deere & Co.

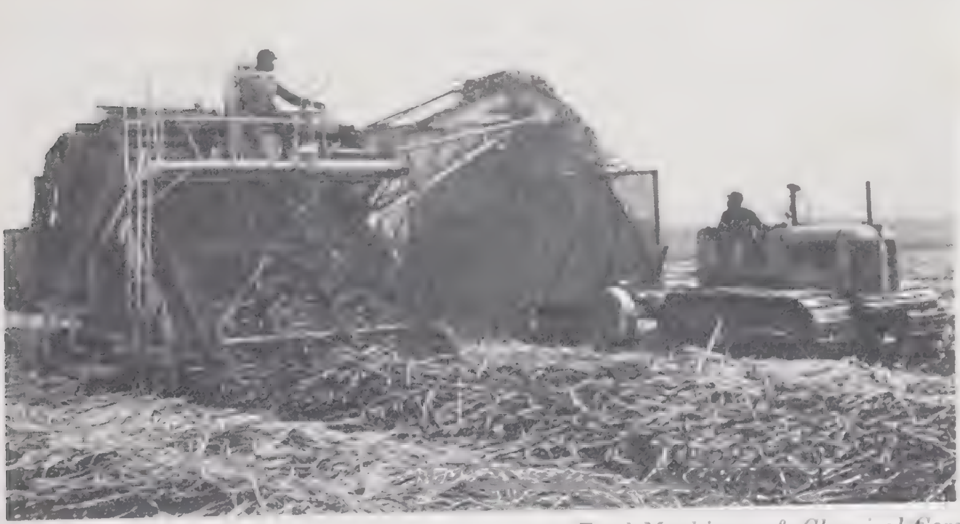
FIG. 14.9. Cut-away drawing of combine. The ground driven reel, *A*, divides the grain and holds it to the cutter bar, *B*. The cut grain is gently elevated by platform canvas, *C*, which, together with feeder, *D*, delivers grain in a thin, even stream to the extra-wide rasp-bar cylinder, *E*, As the grain travels between cylinder, *E*, and concave and open-bar grate, *F*, and back against beater behind cylinder, *G*, up to 90 per cent of the separation takes place. The grain falls through open bar grate to shoe pan, *K*, and is moved back to shoe chaffer—grain is not remixed with straw to overload straw rack. Beater, *G*, deflects grain down through the front end of the straw rack, and passes the straw onto full width straw rack, *I*. Curtains, *H*, deflect and retard straw and grain so full length of rack is utilized. During its rearward movement, the remaining grain falls through cells in rack onto grain conveyor, *J*, and is delivered back to shoe pan, *K*, which moves it to front end of chaffer. Deflectors on shoe pan, chaffer and shoe sides distribute grain evenly over the entire cleaning area. Straw is then tossed out on the ground in a wide, even spread. A blast of air from fan, *N*, is directed by deflector, *O*, against shoe chaffer, *L*, and shoe sieve, *M*. This blast, with the aid of chaffer and sieve agitation, blows chaff away and moves the tailings to tailings auger, *P* This auger carries tailings to tailings elevator, *Q*, which conveys them to auger, *R*, where they are delivered to the center of the cylinder for re-threshing. Clean grain, after dropping through shoe chaffer, *L*, and shoe sieve, *M*, is carried by clean grain auger, *S*, to elevator, *T*, on opposite side of combine and elevated into grain tank.

"bread basket" states, the flax fields of Minnesota, the crimson clover fields of the Old South, and the flower gardens of California—in other words, "from alfalfa to zinnias" as one enthusiastic agricultural engineer has expressed it. Not only do these machines harvest a wide variety of crops but also perform equally effectively either in straight combining (which means harvesting the standing crop) or in windrow harvesting (where the crop has been previously cut and piled in rows normally called "windrows". In the wheat fields of Kansas, it is not uncommon to see a series of self-propelled combines at work. On smaller farms, combines are usually propelled and drawn by the versatile farm tractor. It is not possible to depict the manifold (combined) operations by the mere photograph of a combine at work in a field. Accordingly, there is provided in Fig. 14.9 a "cut-away" view of a combine in action.

Highly mechanized operations are used extensively in the harvesting of sugar cane. The cane is cut, windrowed, and then picked up by self-propelled harvesting machines. These are equipped with conveying mechanisms to load the cut cane into detachable bodies with woven wire sides and false bottoms which are hauled in trains by tractors, or into mammoth powered trucks equipped with huge pneumatic rubber tires (see Fig. 14.10).

Animal Products

In any modern test discussing the materials handling aspects of food harvesting operations, it is not possible to exclude milk. The dairy industry, owing to the readily perishable character of its basic raw material—milk—has had to develop highly sanitary methods of production. For a



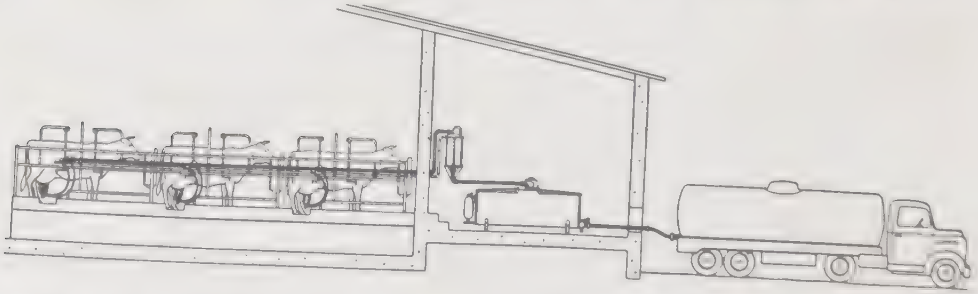
Courtesy Food Machinery & Chemical Corp.

FIG. 14.10. Sugar cane harvester loading from windrow of cut cane.

period of many years, the term "parlor milking" was used to describe a rather elaborate and apparently costly series of materials handling operations. This method of harvesting the milk crop appealed to certain dairymen because their customers could watch the milk being produced under practically ideal conditions. However, what was started with some misgivings as a luxury performance suddenly turned out to be both intensely practical and reasonably economical.

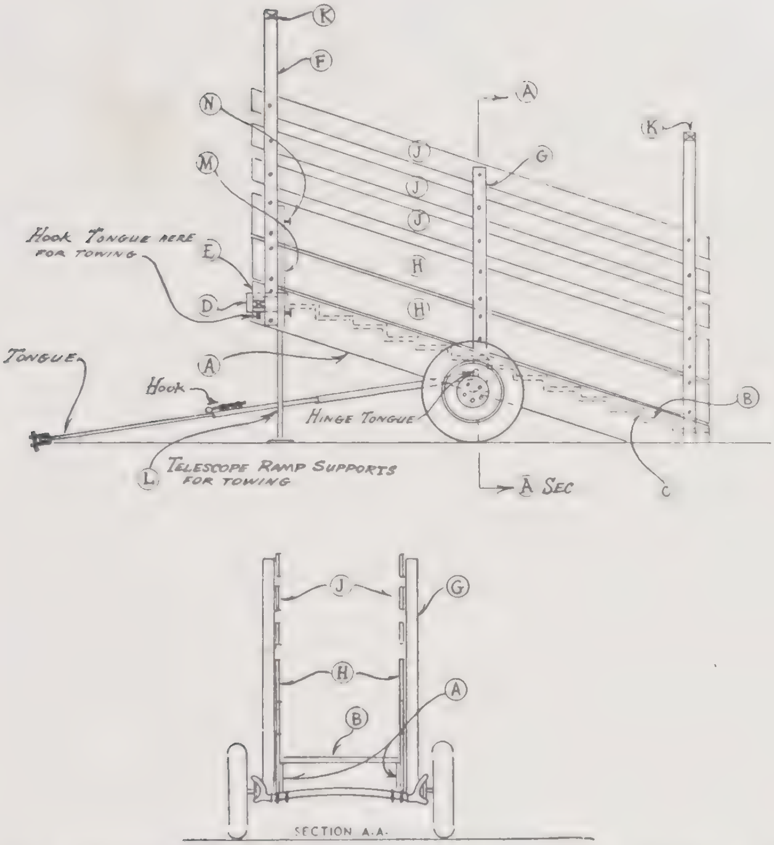
Cows when ready to be milked by machine are brought either into a separate room for washing the udders and teats or are so cleaned right in the milking stall, which is constructed at the proper height for this purpose. The more modern installations provide for rapidly conveying the milk through a stainless steel pipe system whereby it is collected in bulk cooling tanks or some convenient containers in the milkhouse (see Fig. 14.11). As soon as the cow is milked, the milking machine unit is removed, rinsed, and attached to the next cow for a repeat performance. There are, of course, all manner of variations or modifications of milk handling equipment layouts. Instead of the intermittent operation suggested above, it is possible to collect the milk in a receptacle holding the entire milking of one cow. Upon completion of the milking this receptacle is taken to a centrally located area for cooling. The collected milk is then poured by hand into a holding vat or over a surface cooler from which it drains into pails or transport cans. On the other hand, the milk might be delivered directly by appropriate pipeline to a cooling or holding tank for subsequent can filling operations. Such tanks are equipped either with a self-contained cooling condenser assembly or one located in some remote area for servicing several tanks.

Another important phase of the materials handling aspects of harvesting operations is assembling livestock prior to their shipment to market. This is easily done with the proper farm layout of holding and sorting pens, loading chutes, etc. A portable chute developed by the Union Stock Yard and Transit Company of Chicago has incorporated the stair-step principle



Courtesy The DeLaval Separator Co.

Fig. 14.11. Modern milking installation permitting machine milking of cows plus immediate transfer to cooling and collecting tank. The tank provides for convenient pick-up by transport truck for conveyance to processing plant.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SECTION A-A

FIG. 14.12. Portable chute for loading cattle. *A*, jacks; *B*, treads; *C*, risers; *D*, bumper; *E*, support; *F*, core, post; *G*, center post; *H*, lower sides; *J*, upper sides; *K*, ties; *L*, telescoping support; *M*, support holders; *N*, clamps for each support.

which has proved so successful in stationary chutes (see Fig. 14.12). A corral permits classifying for size, type, and finish, with a minimum of excitement and weight loss. For best results, livestock intended for early marketing should be sorted a day or two before loading, not only because lots that are carefully sorted are always more attractive to buyers, but also because extra moving and handling of livestock immediately before loading often lead to crampiness or weakened physical condition.

Many unnecessary losses are caused by improper handling of livestock both in the gathering and marketing areas. Indeed, the importance of proper handling becomes apparent when it is realized to what extent our potential meat supply is annually reduced by disease, parasites, and careless practices. The meat lost in 1951, for example, would have fed a city with a population of approximately 114,000 for one year. In nationwide bruise studies in 49 packing plants, of 664,221 hogs tested 10 per cent were bruised with an average loss of $1.83 per head. Such bruising was caused by striking the animals on meaty portions of their bodies with canes, whips, or clubs, and by kicking them on the hams or sides. Injuries were also caused by prodding, crowding, trampling, fork and nail punctures, etc.

With the constant technological advances being made in food processing, we have witnessed in recent years a growing popular demand for fish and other marine products. In the period from 1930 to 1952, the total annual catch in the United States has risen from slightly more than 3¼ billion to nearly 4½ billion pounds. As a source of food, our oceans and inland waters might conceivably yield still greater crops as their care and culture are expanded. Some marine products—notably shellfish of various types—are cultivated successfully. The materials handling methods employed in harvesting fish and fish products are perhaps among the most ancient of all known mechanical arts. There are a great variety of fishing methods from lines and hooks to the many kinds of gear including nets (seines) of various and sundry descriptions and purposes, trawl lines, wheels, weirs, otter trawls, traps of all sorts, dredges, tongs, rakes, and spears employed in commercial fishing dependent upon the species being sought, locations, and other factors.

Significant changes are taking place in the methods of fishing and in the processes of preparing the fish for market. Preserving fish aboard ships by freezing for later defrosting, processing, and refreezing ashore is contrary to the rather widespread popular belief that once fish is frozen it should never be refrozen. The ability of fish flesh to withstand the process of freezing, thawing, and subsequent refreezing is in large measure governed by the condition of freshness of the fish at the time of the initial freezing.

Courtesy Standard Oil Co. of New Jersey

FIG. 1.13. Shrimp fishing in the Gulf of Mexico. This shows swinging out the 95 x 55 foot trawler just before bringing it in to empty.

TRANSPORTING

It is important in the materials handling of harvested food products that they be transported expeditiously and carefully. This, however, is much easier said than done. The transport of fruits, vegetables, grains, and animal products from their points of concentration or harvesting to the food processing plant entails a tremendous amount of detail, the importance of which is often overlooked because its implementation is usually taken for granted. It is so obvious that perishable foodstuffs must be quickly and carefully handled that when there is a breakdown in delivery or transport facilities everybody concerned is inclined to overlook essentil details by relying too heavily on a "let George do it" attitude. For maximum retention of quality in any food product, meticulous attention must be given all aspects of transport. Formerly most transportation techniques relied heavily on manual labor (and in so doing provided repeated visual inspections); today, economic considerations plus shortages of manpower have forced an increasing mechanization of incidental operations.

Fruit and Vegetable Crops

It will be recalled that in discussing the harvesting of various fruit crops, repeated mention was made of lug or field boxes or crates. Such containers are by no means used exclusively for all fruit crops. As a matter of fact, the annual movement of fresh fruits and vegetables to market has necessitated their packing in some kind of container, which is usually the merchandising unit. Actually, the containers used in marketing fresh fruits and vegetables are of vital importance both to the industry and to the general public. Nevertheless, in growing areas where the produce harvested is processed and not sold fresh, wide use is made of lug boxes for transporting various fruit and vegetable crops to local processing plants. On the other hand, many processing plants located in areas remote from certain fruit crops find it convenient to buy their supplies packed in standard marketing containers. When such standard containers are used, it is often convenient and economical to reuse them as lug boxes are reused.

It should be emphasized that any boxes or other containers used in the transport of fruit or vegetable crops must be so used as to avoid cracking, fracturing, crushing, or bruising their contents. Fruit juices especially are excellent media for mold growth, especially if they are exposeed to the atmosphere in the field, during transit, or on the receiving dock of the processing plant. Such containers, therefore, should be thoroughly washed, rinsed, and dried before reuse if any fruit they contain has become damaged enroute. Even under the best circumstances, these containers will become contaminated with molds, yeasts, and bacteria which should emphasize the necessity of handling produce carefully. Whenever the natural protective barriers of a fruit are fractured or penetrated, spoilage will surely and quickly ensue.

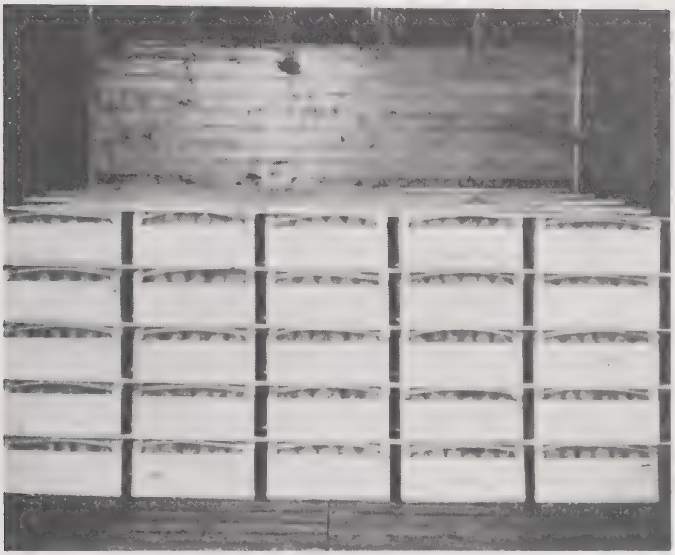
Engineers not trained in bacteriology might assume that since moldy fruit loses its individual identity in processing, too much emphasis can be placed on care in handling. Such is definitely not the case. For, aside, from the fact that contaminated food is offensive to the esthetic sense, there is an implied warranty in the law that food per se is fit for human consumption. Mold mycelia counts (and other objective tests) may be applied to processed foods by the U. S. Food and Drug Administration at any time as indices of relative degrees of cleanliness. Legal seizures and the public notices attendant upon their realization as well as subsequent court actions do not create confidence in the performances and products of any food processor. Then too, courts are tending more and more to place the responsibility for failure to meet minimum standards of quality in food products upon the supervisory personnel rather than upon the management officers themselves. Consequently, food engineers must be ready at all times to defend their professional status in the event of any obvious lapses of proper discretionary functions.

The containers used for shipping packed fresh fruits and vegetables may be divided into four principal classes: (1) baskets, (2) crates and boxes, (3) barrels, and (4) sacks. A fifth class, drums, has a limited use.

There are five types of baskets: (1) berry and till baskets, (2) hampers, (3) round stave baskets, (4) splint or market baskets, and (5) climax baskets. Crates and boxes are constructed of rotary-cut or sawn material. The ends, sides, tops, and bottoms may be solid, paneled, or slatted, in various combinations of single pieces and cleated units. They are usually assembled with nails although many crates are bound together with encircling wires or straps and closed with interlocking loops. Corrugated and solid fiber boxes are included in the crate and box classification.

Barrel construction is usually classified as stave or veneer; some barrels have wooden heads in both ends and others are closed at the top with cloth or burlap. Sacks are generally made of burlap, but many are now made of cotton sheeting and of paper. Open-mesh sacks of cotton net or paper net are extensively used for such fruits and vegetables as apples, cabbage, citrus fruits, green corn, onions, etc. Drums have been used in the past for certain varieties of grapes packed in sawdust but are now used chiefly for brussels sprouts.

It should be mentioned in passing that of the four classes of containers for fresh fruits and vegetables, Federal standards have been established for only two—baskets and barrels. The only other standards are those which have been established by state law or regulation and those which have become virtual standards through common usage.

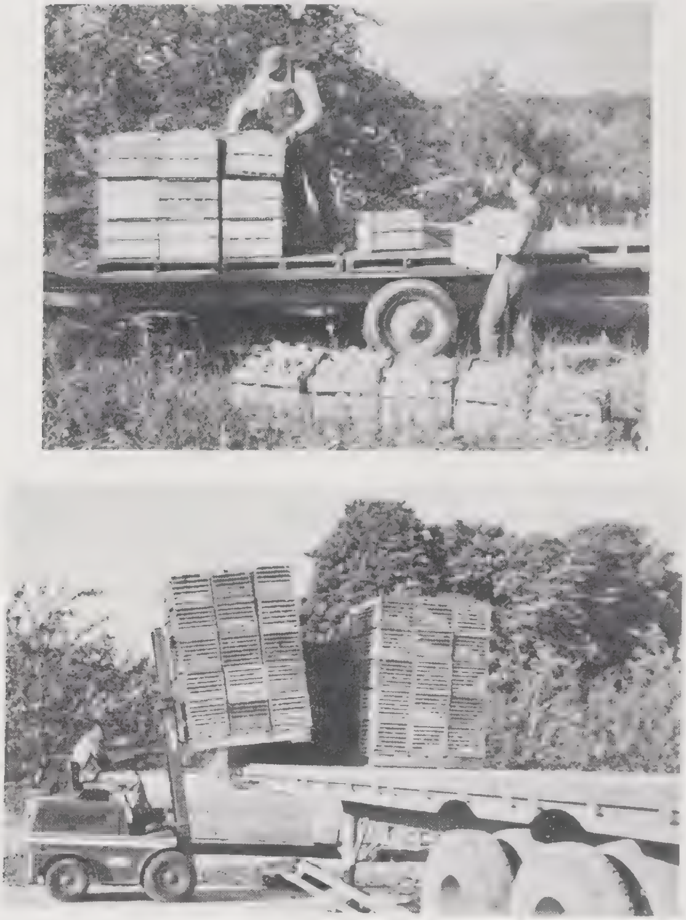


Courtesy Production & Marketing Administration USDA

FIG. 14.14. Lug boxes of tomatoes in partly loaded refrigerator car. Note the heavy cleats both under and over the ends of the cover, which tend to protect the bulge pack when the boxes are stacked.

In transporting field crops, all manner of conveyances are utilized: airplanes, railroad boxcars, refrigerated cars, flat cars, and open gondolas; and automobile trucks of both the open and tank type. The popular and versatile farm tractor, or jeep for that matter, is used extensively in hauling crops from out of the fields and orchards on trailers. These trailers are often equipped with special oversize tires, to enable them to operate in fields as well as on roads. In addition to various and sundry types of automotive hauling and delivery trucks, increasing use is made of many kinds of lift trucks for facilitating the transport as well as the receiving of fruit and vegetable crops. In the latter cases, the filled lug boxes or crates used in harvesting the crops are stacked on pallets as they are loaded onto trailers in the field; this facilitates their reloading onto trucks for transporting to processing plants or markets as well as their subsequent unloading at their receiving points (see Fig. 14.15).

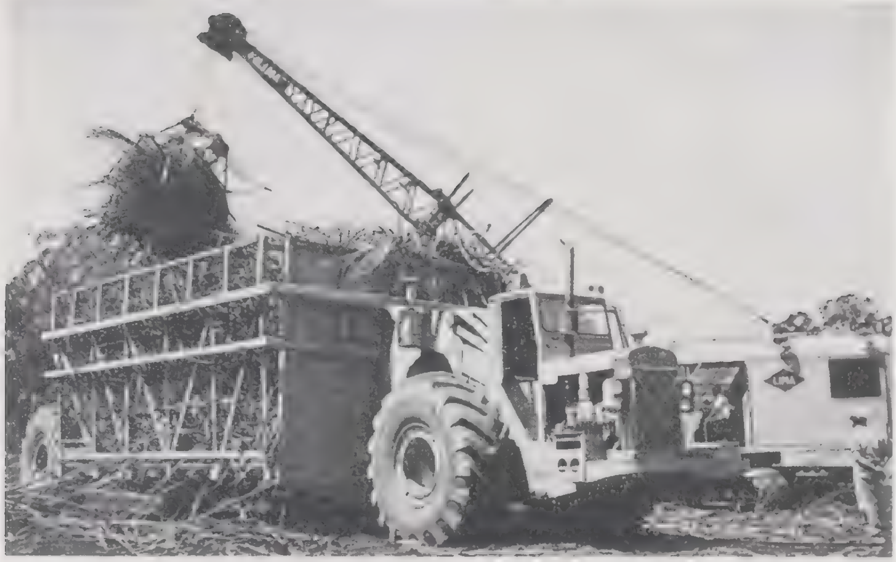
In another transportation system, smaller pick-up trucks gather products from a farm or several farms in lug boxes for conveyance either to a packing plant or to a concentrating point for collecting a substantial load of several tons for transport to a processing plant. It is important to keep in mind that fresh fruits and vegetables are either packed for merchandising "as is" or processed into other food products. In the former case, the fresh products are usually handled in smaller units such as lug boxes or crates as well as standard containers, whereas in the latter case, there is the tendency to handle



Courtesy Michigan State College

FIG. 14.15. Top view shows loading of fruit onto orchard trailer. Note that the crates are being stacked on pallets which will make it possible to handle 18 crates as a unit load. Bottom view shows loading of semi truck with the aid of a fork-lift truck, 30 crates being handled as a unit load.

in bulk when so doing will not impair the quality of the produce by crushing, bruising, or other physical injury. Oranges, for example, harvested for packing are gathered in field boxes for transporting to a packing house by means of small pick-up trucks whereas those destined for processing into frozen citrus juices are gathered at some concentrating point for bulk conveyance to a processing plant by means of large semi-trucks or trucks. Actually the softening the oranges might undergo in transit to the processing plant really preconditions them for ready extraction of the juice. In the case of packing for distribution as fresh fruit this practice would be definitely detrimental, as their keeping quality would be markedly reduced. Because the fruit used for juice recovery processes consists largely of culls which are usually of the relatively smaller sizes that ship better in bulk than



Courtesy Hawaiian Sugar Planters Assoc.

FIG. 14.16. Transporting harvested sugar cane.

choice fruit, and because it is processed promptly following receipt, there is no problem of physical defects which make fresh fruit unacceptable.

In the case of many vegetables it is possible to load trucks directly in the field at the time of harvesting such crops as beets, for example (see Fig. 14.7). Sugar cane is likewise handled by loading into trailers (see Fig. 14.10), freight cars, or special trucks equipped with huge bodies and mammoth pneumatic tires (see Fig. 14.16).

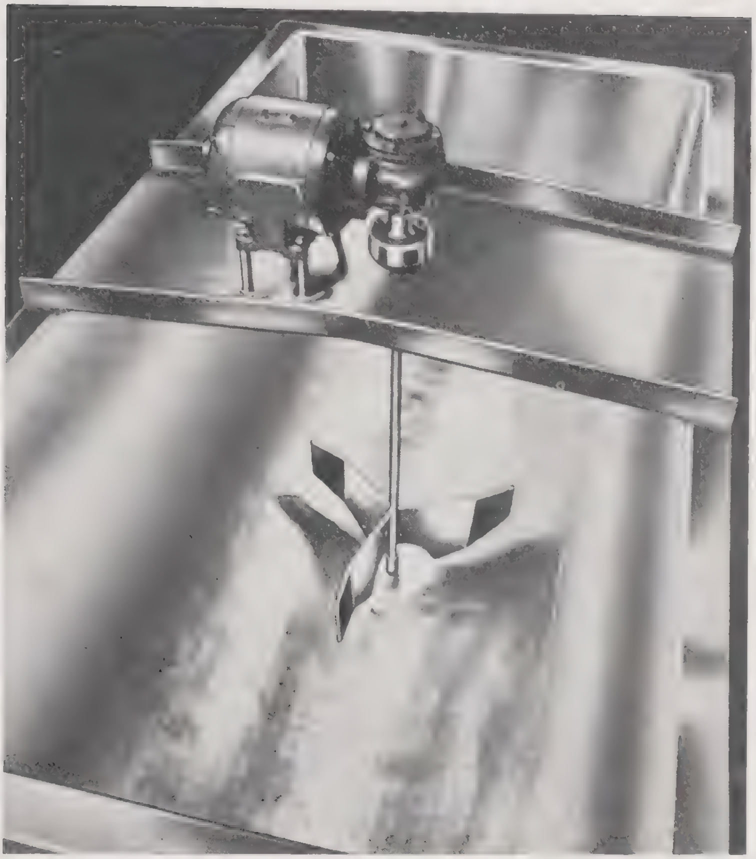
We have attempted to show the many means, methods, and conveyances utilized in transporting harvested crops of fruits and vegetables from the field to the packing house, concentrating point, or processing plant. It is not possible to cover all the materials handling techniques or equipment involved; however, it should be apparent to the reader from what has been presented that increasing attention is being paid to the details of materials handling for expediting the harvesting and the transporting of foods and doing this as economically as possible. It will be well to remember that in the mass production, there is ever the race between the natural processes of spoilage and the artificial processes of preservation. It is, in fact, conceivable that the conservation of essential food might be measurably advanced by still further mechanization of harvesting and its transport, as any hastening to the packing house or to the processing plant which might be achieved could increase the ultimate yield. The tremendous amount of food wasted in the United States is not wholly accounted for by that which goes into garbage pails for there still is a considerable loss of food in the field and at the packing house and the processing plant that could be recovered by better materials handling methods and equipment.

Animal Products

In the dairy industry, transport is of vital importance owing to the inherent perishability of milk. The original quality of the milk must be protected from cow to consumer if the farmer and the processor are to receive maximum benefits from their efforts and investments. One of the most important developments in milk production which has occurred during the past decade has been that of the refrigerated farm tank system for bulk cooling and tank truck pickup as depicted in Fig. 14.11. Tank trucking of milk from farm to processing plant has proven profitable to both the milk producer and the milk processor where a tank truck pickup route can be organized with a sufficient number of dairy farmers producing appreciable quantities of milk. Where farm cooling tanks can be utilized, it is possible to pick up milk every other day with no apparent impairment of quality although there are some municipalities where such practices are frowned upon.

The farm cooling tank principle appears to be gaining adherents even in those areas where the daily volume of milk production is not adequate to justify a tank truck pickup route. In such cases, or in advance of a completed tank truck pickup route, the farm cooling tank can be set up high enough to permit gravity filling of milk transport cans, or a suitable pump can be used. The first milk entering the farm cooling tank is rapidly cooled by contact with the large area of refrigerated bottom surface. The added milk is cooled both by mixing with the previously cooled milk in the tank and by the continued effect of the refrigerated surface, thus maintaining the milk at a low temperature during the milking operation. A low-speed agitator provides proper circulation necessary for fast cooling, and thorough mixing for sampling (see Fig. 14.17). The farm cooling tank can be provided with thermostat control for automatic operation of both the compressor and the agitator—the thermostat being set to cool and maintain the milk at the proper storage temperature, usually 38°F.

While the tank truck pickup system is increasing, the great bulk of our milk supplies are still being transported from farm dairies to processing plants in the familiar 8- or 10-gallon milk transport cans mainly of hot-dipped tinned iron construction, although aluminum and stainless steel milk cans have been successfully used. Improvements in milk can construction have eliminated the soldered seams at the bottom, breast, and neck of the can. More recently, streamlining the breast of the can to eliminate the sharp bend at breast and neck has simplified the cleaning problem and also the draining of its contents upon emptying, leaving less milk

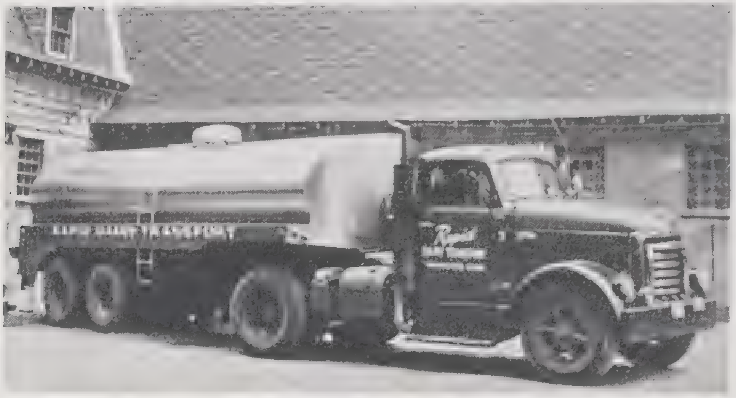


Courtesy Creamery Package Mfg. Co.

FIG. 14.17. Top view of farm cooling tank. Note the refrigerated bottom surface area and agitator for circulating milk to facilitate cooling as well as assure proper mixing for sampling.

clinging to the inside surfaces. Milk transport cans filled with their cooled milk are usually conveyed from the farm to the processing plant in covered trucks. The tank trucks are normally stainless steel insulated tanks mounted on a suitable truck chassis designed with due consideration of the load weight and distance characteristics involved in order to assure the delivery of cold, raw milk (normally 36 to 40°F) to the processing plant with no danger of churning or souring en route (see Fig. 14.18).

With reference to the transport of livestock to market or to processing plants, the comments which were offered in the discussion of incidental details of their gathering or collecting apply equally to their transportation. Overcrowding and injuries due to careless handling during transportation all contribute to a lessening of the quality of the meat products recovered. Railroads are heavy shippers of livestock, although motor transport is daily gaining shippers. Care in the design of the shipping conveyances used



Courtesy Creamery Package Mfg. Co.

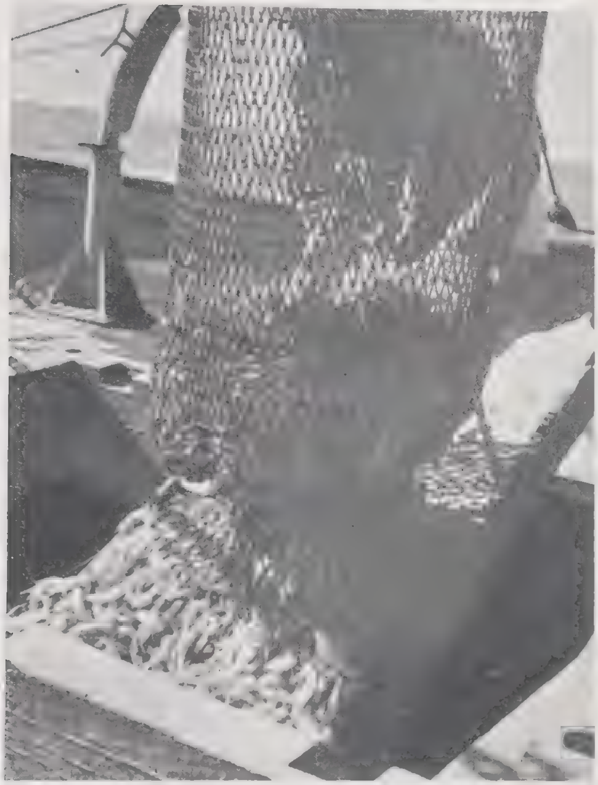
FIG. 14.18. Modern tank truck pickup of milk supplies. This insulated stainless steel tank mounted on a motor truck chassis assures the delivery of cold raw milk from the farm dairy to the processing plant.

in their transport contributes to their proper delivery with a minimum of injuries which impair quality. Such details are receiving increasing attention as the meat packing industry is conscious of the enormous losses attributable to the maiming or injury of animals en route to market or packing plants.

In the transport of fish, it has been common practice to pack the fish in ice in the hold of the fishing vessel until it returns to port. This will keep fish satisfactorily for a few days if properly iced (see Fig. 14.19.) However, the development of more successful methods of fish preservation aboard vessels is regarded as of extreme importance in view of the wide variance in quality of fish brought into port and the subsequent losses resulting from less desirable fish. The ideal method appears to be to quickly freeze the fish immediately after catching and to bring it into port in that condition. It is then sold to commercial fishermen for thawing and further processing for the consumer market. Within recent years, fishing vessels have been built with mechanical refrigeration facilities for keeping fish in a perfect state of preservation until unloaded at the docks. However, there still remains the engineering problem of designing freezing equipment of satisfactory size and efficiency before there will be any extensive outfitting of large trawlers that go down to the sea for fish.

RECEIVING

In the assembly of raw materials for the production, preparation, processing, handling and distribution of foods, obviously the methods of receiving them are of paramount importance. It is at this point in the preparation of processed foods that natural protective elements will be replaced with artificial means of conservation. Consequently, proper care must be



Courtesy Standard Oil Co. of New Jersey

FIG. 14.19. Shrimp recovered from the Gulf of Mexico being emptied from the wash-net into the slide. This shoots them into the hold of the boat where they are iced and stored during transport to market.

exercised lest that which has been expended in harvesting and transporting be lost. Again, time is of the essence; for in receiving operations, the raw food material becomes exposed to the many biological, chemical, and physical influences that can hasten its spoilage unless properly guarded against.

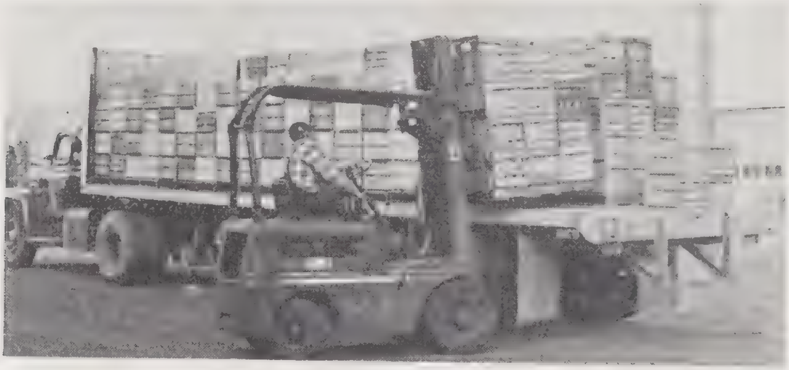
Accordingly, receiving of harvested foods will be discussed in much the same manner as harvesting and transporting, following the same general outline of crops and products.

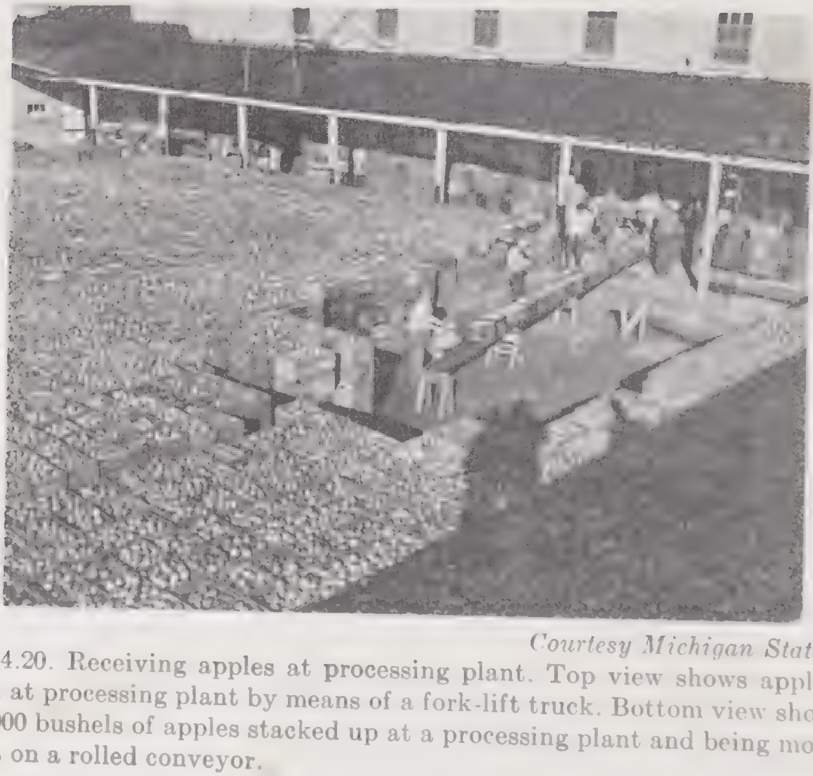
Fruit and Vegetable Crops

The fresh fruit and vegetable distributive industry, as well as the processing industry, have only recently begun to improve the materials handling methods of unloading, conveying, stacking, and distributing raw products. Even today, the bulk of the produce is still handled either manually or by the most elemental types of equipment just as it was two or three decades ago.

Before proceeding with the discussion of improved methods, the reader is referred to the section on transporting wherein lug or field boxes or crates and standard containers are discussed. It is important to keep in mind that in processing plants, there is an essential difference between the handling of fruits and vegetables in general containers or in bulk and their handling in *merchandising* units. The latter invariably calls for some approved type of standard container not necessary or perhaps even desirable in handling these crops for processing.

Generally, in any receiving operation there is the necessity of proper segregation of produce to permit its adequate grading. Where lug boxes or crates are used for transporting the crop to either the packing house or the

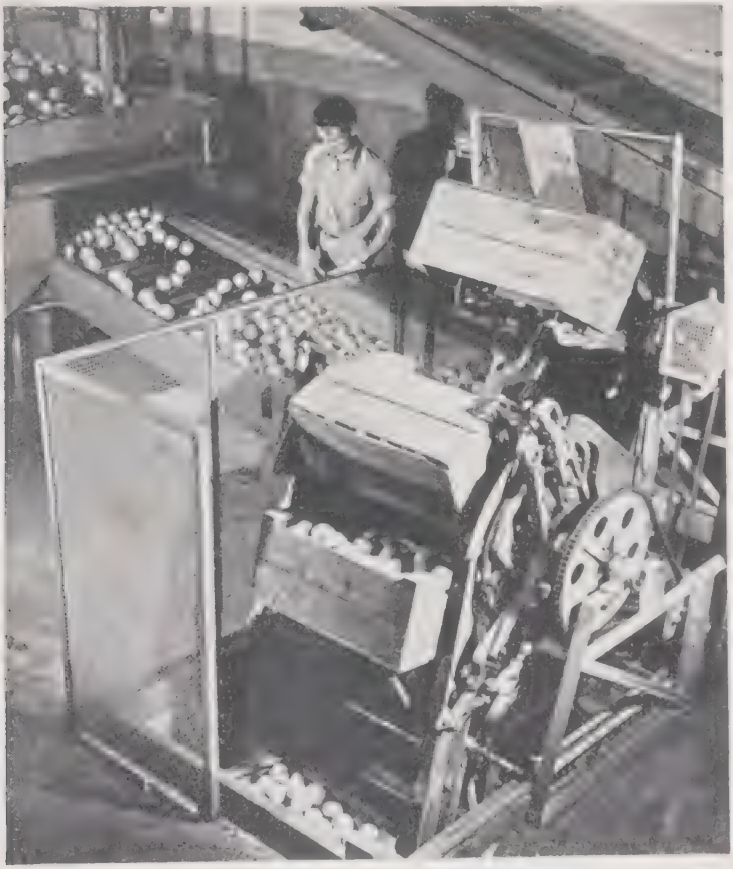




Courtesy Michigan State College

FIG. 14.20. Receiving apples at processing plant. Top view shows apples being unloaded at processing plant by means of a fork-lift truck. Bottom view shows more than 10,000 bushels of apples stacked up at a processing plant and being moved into the plant on a rolled conveyor.

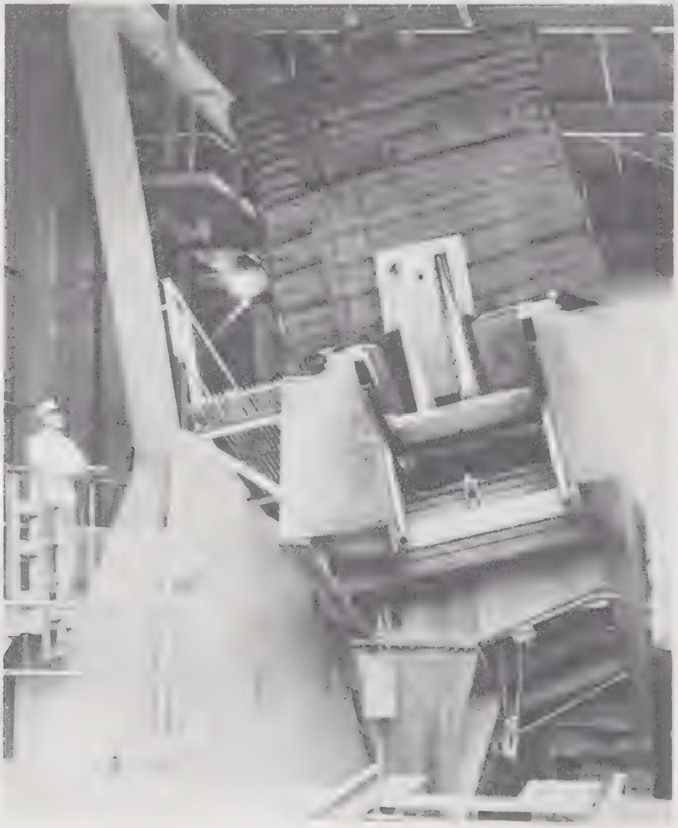
processing plant, their unloading and stacking is a primary operation. Depending upon whether the transporting conveyance is a railroad car or a motor-truck, there is the necessity of proper storage or sorting space such as a concrete apron or the floor of a warehouse. Some tractable, smooth-surface area is indispensable for the effective handling of produce to be received. The efficiency of any receiving operation will be markedly increased if the loads being received are palletized, permitting them to be unloaded by fork-lift trucks. A modern practice at processing plants is to unload the palletized load of fruit and stack it at some convenient spot which will later permit its movement into the plant by belt, chain, roller, or bucket conveyors. Such basic materials handling operations are depicted in Fig. 14.20. On the other hand, in a fruit-packing house field boxes filled with fruit may be conveyed to some convenient receiving spot where they are mechanically emptied, the empty boxes being brought to the unloading area for return to the transporting truck (see Fig. 14.21).



Courtesy Sunkist

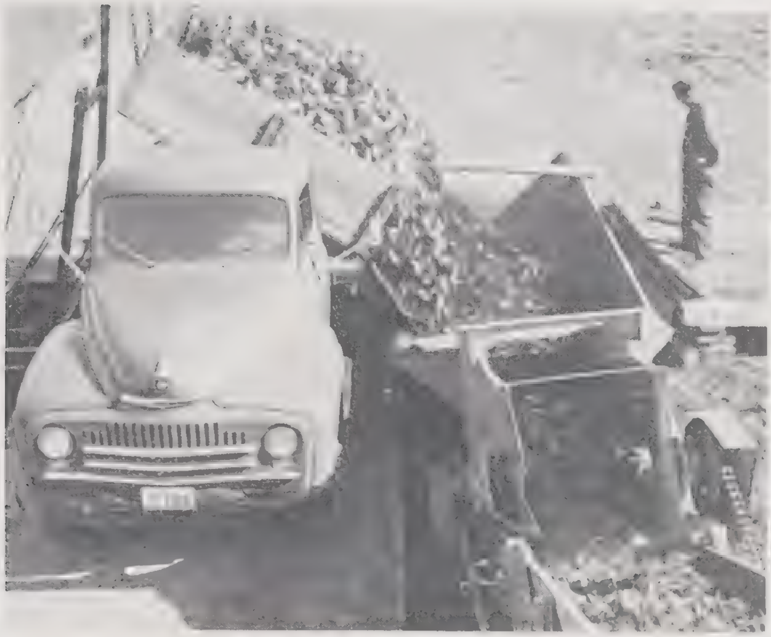
FIG. 14.21. Field boxes of oranges being received in packing house directly from grove.

Free-flowing raw material such as grain received in bulk in box cars at the mill can be spotted on a siding and the grain discharged from the car into a pit located in front of the head house. The pit is covered with open metal grids, both as a safety device and to exclude foreign materials. That portion of the grain which will not flow from the car to the pit by gravity when the car door is opened must be shoveled or plowed out. A modern method is to use a car-dumper which up-ends the loaded boxcar and tilts it first to one end and then to the other in unloading grain through opened doors. A car-dumper unloads, automatically, eight to ten boxcars an hour (see Fig. 14.22). Grain is also readily unloaded from motor trucks inside a grain elevator by dropping through a grate in the floor; it is picked up by bucket conveyors and carried to the top of the elevator where it is dropped into bins. Vegetables can be similarly received at a processing plant by unloading motor trucks into hoppers feeding flight elevators which convey the vegetables into the processing plant (see Fig. 14.23).



Courtesy Quaker Oats Co.

Fig. 14 22 This up-ended boxcar represents the change from hand methods of unloading grain, to the easier, faster method of the mechanical car-dumper. Grain pours through the open door of the boxcar in a steady stream



Courtesy International Harvester Co.

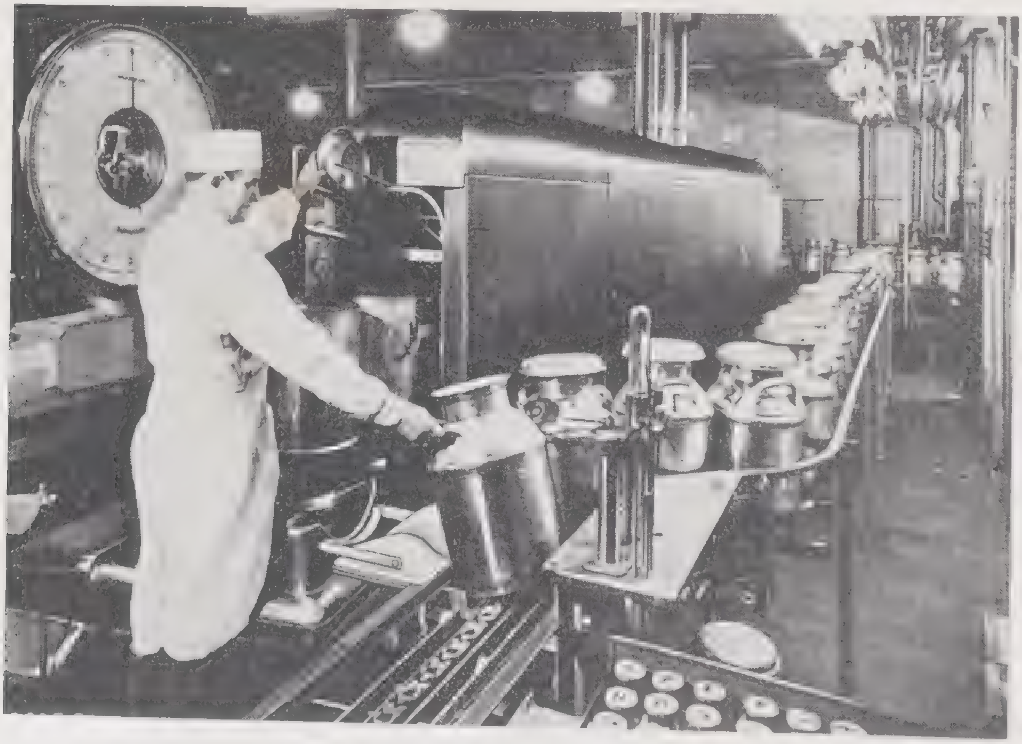
FIG. 14.23. Sugar beets being received at refinery from transport truck which was loaded in field of nearby vicinity.

Animal Products

Receiving operations in the dairy industry have been highly mechanized. In our previous discussion of the transporting of raw milk supplies, we pointed out that one of the most important developments of recent years had centered around the tank truck pickup system. Obviously, when a dairy plant is serviced with this type of raw product delivery, the means of receiving the milk is the relatively simple one of pumping it from the truck tank through sanitary lines into the plant storage tanks where the cold raw milk is held prior to its processing.

While there is a trend to more and more tank truck pickup and delivery of milk supplies, the great bulk is still transported from farm to dairy in the familiar 8- or 10-gallon transport can. The farmer filters and cools his milk before filling the transport cans which are usually picked up daily by motor trucks. Inasmuch as each truck goes from farm to farm picking up the farmers' daily supplies of milk, it is customary for the transport cans used in delivering his supply to be marked with some identifying number. When the truck driver delivers the load of milk to the dairy plant, it is generally unloaded onto roller or chain conveyors which transfer the full cans to the receiving area. The conventional receiving operation provides for dumping the milk from the transport can into a receiving tank of sufficient size to contain the contents of several cans. Immediately after the milk is emptied into the receiving tank, the drained can and its cover are placed in an automatic can washer which cleans and sanitizes them. They are then returned from the can-washer discharge by another conveyor back to the truck to be exchanged for the filled cans of raw milk on the next day's pickup. Not only are daily records kept of each day's shipment of each farmer's supply but automatic sampling of the mixed milk in the receiving tank is provided, in proportionate amounts to the volumes received. Such samples are transferred to labelled sample jars and the composite samples analyzed for their milkfat content at regular intervals (see Fig. 14.24).

In the meat-packing industry, the receiving point is generally referred to as the "killing floor" or the "killing room." The animals to be slaughtered are driven into pens holding only a few animals so that they are crowded and movement is restricted. From these pens they pass through a narrow passage to the killing room. In some cases the animals are stunned by hitting them on the forehead with a round-headed sledge hammer. Hogs are normally driven up a long ramp to a shackling pen. Here, two strong-armed



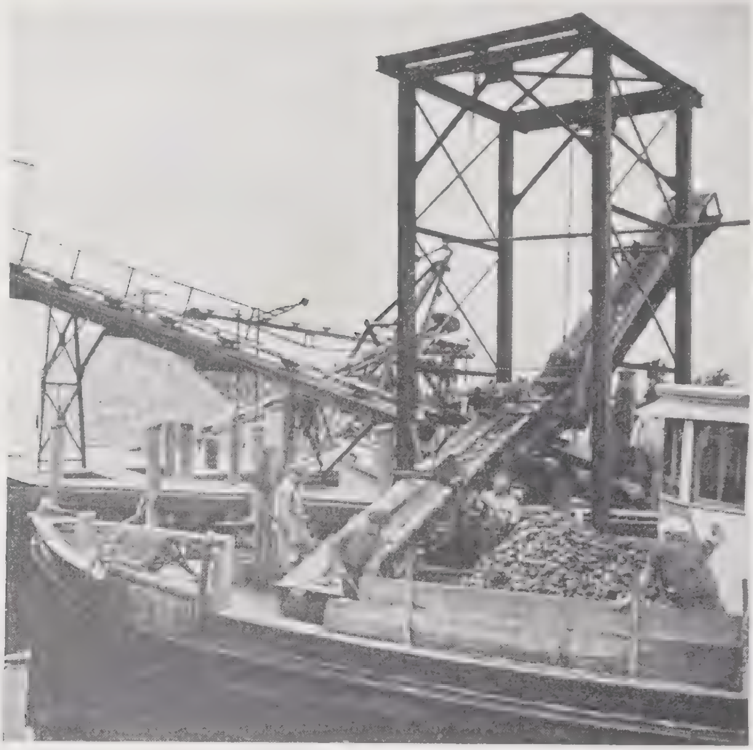
Courtesy Lathrop-Paulson Co.

FIG. 14.24. Receiving milk in transport cans. The operator has just removed the cover from a filled can of milk which he is tilting preparatory to dumping into the receiving tank just in front of his knees. The large dial to his left indicates the weight of milk contained in the receiving tank. Mixed milk is automatically sampled by the apparatus just to the right of the tilted can. The sample bottles with their identifying numbers are seen in the rack at the lower right hand corner of the picture

men perform the hectic job of shackling a chain to a rear leg of each animal. In either case, the shackled animal is hoisted onto an overhead rail with a trolley arrangement which carries it through a sticking and bleeding area where the highly accurate incision is made to sever an artery deep in the throat. In the case of hogs, a recently developed immobilizing technique whereby the animals are "put to sleep" with carbon dioxide gas prior to sticking, thereby permitting "belt-level" shackling and quiet, controlled bleeding of each subdued, railborne animal. Some of the apparent advantages of this immobilizing method are that it (1) greatly diminishes animal fatigue thus assuring top-quality meats, (2) assures more accurate sticking which reducing spattering, (3) increases animal respiration thereby increasing blood recovery, and (4) permits uniform rail speed affording better synchronization with other plant operations. While this new method has been applied only to hogs as a packing house practice, it is probable that it will in time be utilized in immobilizing other meat animals because of the demonstrable gains in operation and in working conditions.

The receiving of fish and fish products employs all manner of materials handling equipment—slides, sluices, conveyors, hoists, trucks, and scoops of all kinds, not to mention shovels, gaffs, forks, or pughs. The latter are not employed as commonly as they once were, but their use still persists in many quarters. Actually, the use of gaffs and forks, or pughs should not be tolerated as they puncture the skins of fish and leave wounds where microorganisms can enter to hasten deterioration. Actually, fish are notable for the speed with which they decompose when taken from the water. Therefore no practice in their harvest, transporting, or receiving shall be allowed that will hasten their quality impairment. In this connection, and to emphasize why autolysis is so rapid in fish at ordinary temperatures, it should be pointed out that fish are cold-blooded animals, i.e., they have no heat-regulating systems. For this reason, as well as the fact that the habitat of the fish is not naturally warm, the enzymes within their body systems are accustomed to function at lower temperatures than those of warm blooded animals. Also, the flesh of fish differs in physical and chemical structure from that of mammals. Bacterial invasion is through the gills into the blood, from the slime of the skin on and between the scales, and by way of the intestinal tract. Furthermore, fish skin is not as resistant to penetration and to desiccation as the skin of land animals. While fish can be preserved for short periods of time by being packed in ice, such practice is only a temporary expedient; the chief means of preserving fish for longer periods of time are freezing, thermal processing, salting, smoking, or drying.

In recent years, shellfish have increased in acceptability probably through the extensive operations aship and ashore for processing them promptly after their harvest (see Fig. 14.25). Fresh shrimp and fresh oysters of good



Courtesy Standard Oil Co. of New Jersey

FIG. 14.25. Receiving oysters at Greenport, Long Island. Mechanical conveyor system moves oysters direct from boat to stations within modern processing plant where oysters are sorted and processed for market.

quality may be purchased in many central sections of the United States; they were frozen promptly following their catch and then shipped to their destinations in the frozen condition. It would appear that the market of most fish and fish products could be similarly extended by their quick frozen processing.

ENGINEERING ASPECTS OF MATERIALS HANDLING

The cost of handling raw food materials in their harvesting, transporting, and receiving operations is a substantial portion of the incidental labor costs as well as the basic market prices of the various commodities involved. The methods and procedures followed in performing these operations, therefore, require careful study and appraisal inasmuch as competitive influences are constantly providing the incentives to reduce these costs to the lowest practical level. Actually, the handling of raw food materials does not enhance their value in the slightest. It does, however, constitute substantial insurance in sustaining their quality. Therefore, in the final analysis, materials handling merely adds to the cost of foods and, consequently, any unnecessary handling of raw materials results in higher costs that can not be reclaimed. The same is true, of course, of any unnecessary handling of final food products, whether they are packed or processed, as well as of all food ingredients and supplies.

It should be emphasized that when labor rates were much lower than those which prevail today, the additional costs of materials handling were not too significant. In spite of these circumstances, many handling operations in the various food industries are being performed today in the same manner as they were when the cost of labor was not critical. In addition, modern merchandising requirements have also added additional handling expenses which are all too often lost sight of. Actually, these two conditions result in high unit labor costs that usually are not justified because they are caused by manual handling and rehandling practices based upon relatively small quantities. Materials handling equipment has been developed during recent years that eliminates many individual or piece handlings. Rather, it provides the means of handling relatively large quantities of raw materials, ingredients, supplies, and finished products much more rapidly and decidedly more economically.

Modern materials handling is properly defined as the mechanical movement of materials in volume, in any direction, to accomplish a reduction in labor costs and to increase storage facilities. It can be applied not only to the movement of raw food materials during harvesting, transporting, and receiving, but also to production, packaging, packing, warehousing, and distribution of the finished products themselves.

Obviously, it is the responsibility of every food engineer to carefully investigate the materials handling in all production, preparation, processing, handling, and distribution operations that come within his purview for he can never immediately anticipate the ultimate effects upon the synchronization of the many operations under his control. Usually, careful investigation will reveal many opportunities to reduce operating expenses and when appreciable volumes are involved, invariably modern materials handling equipment will suggest a solution.

Principles of Materials Handling

One of the major factors contributing to relatively high materials handling costs is the failure to balance crew and equipment. Balanced handling is of utmost importance inasmuch as in most instances the accomplishment of one crew member depends on the work done by another crew member. Thus, if there are too few workers at one phase of an operation, a great deal of time will be lost through waiting at another phase of the task, thereby raising the costs for the entire operation. Conversely, if there are too many workers at one phase of an operation, efficiency suffers because of interference with one another, again contributing to relatively high costs. The work should be so synchronized that all members of the crew are always kept busy. *Balanced handling*, therefore, may be defined as that arrangement of equipment and assignment of members of work crews as will keep delay time and total man-hour requirements to a minimum.

Although the unit load principle of materials handling is widely employed in many industrial and commercial operations, it is not in common usage in food industries. However, handling in unit loads is on the increase among many private food companies and probably will be extended as its benefits are more fully realized.

A unit load is made up of several packages grouped together (boxes, crates, etc.) so that they may be handled as a unit for unloading, transporting, stacking, or loading operations, or any combination of these and related operations, rather than as individual packages. A unit load is usually considered to be a loaded pallet or skid, but might also be any load consisting of two or more packages so set together that they can be handled and moved simultaneously as a unit.

We can perhaps illustrate the importance of the unit load principle by a comparison of a materials handling operation performed with two-wheel stevedore type hand trucks without applying the unit load principle, and a similar operation performed with semi-live skids but utilizing the unit load principle. The effectiveness of unit loads will be emphasized in the unloading, transporting, and stacking or warehousing of a carload consisting of 750 lugs of tomatoes using these two different methods.

The use of the ordinary two-wheel hand truck usually does not permit handling in unit loads (although it can be so adapted) because the load is broken up into individual handlings. Normally the sequence of steps in unloading, transporting, and stacking a carload of tomatoes would be as follows:

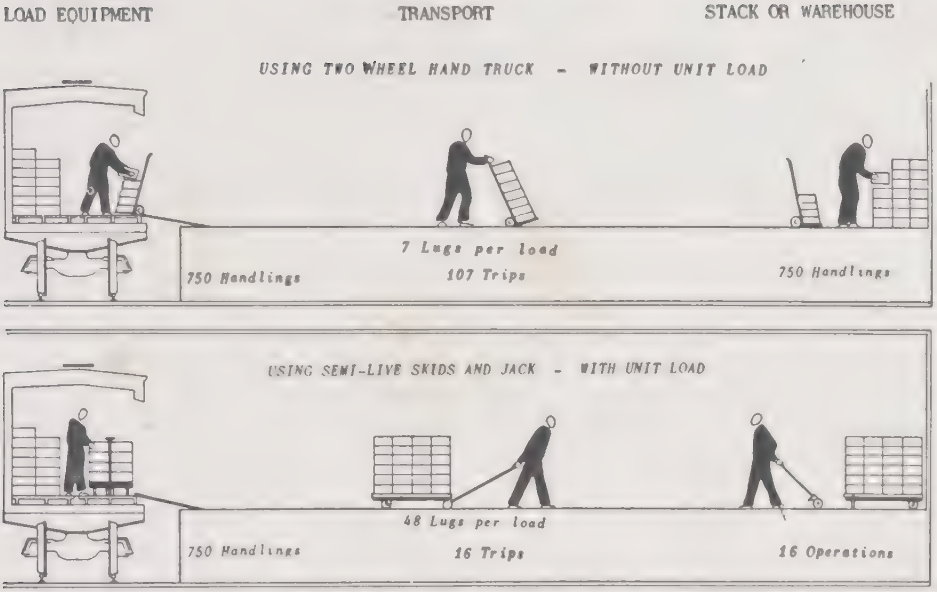
(1) Remove stripping and unload lugs, one by one, from the freight car onto the two-wheel hand truck.

(2) Wheel hand trucks, loaded with 7 lugs each, to the stacking area.

(3) Unload the lugs, one by one, from the hand truck and place in stack.

The above steps are shown graphically in the upper part of Fig. 14.26. To unload and place in storage, the 750 lugs of tomatoes have required 750 handlings of individual packages in the freight car, 107 trips (750 lugs ÷ 7 lugs per trip) from the freight car to the stacking area and return, and 750 rehandlings of the individual lugs at the stacking area.

One of the least expensive pieces of equipment with which unit loads can be handled is the semi-live skid and jack. Dead skids or pallets together with hand-lift or fork-lift trucks can also be utilized for this type of handling. These items of equipment are illustrated in Fig. 14.29. The basic



Courtesy Production & Marketing Administration USDA

FIG. 14.26. Two methods of handling the unloading of a carload of 750 lugs of tomatoes.

steps in unloading the 750-lug car of tomatoes by applying the unit-load principle, using semi-live skids, are as follows:

(1) Remove stripping, wheel empty skids inside car, and unload lugs, one by one, from the car onto the skid (or other equipment), 48 lugs to a skid load.

(2) Wheel the loaded skid (a unit load) to the stacking area.

(3) Place the loaded skid in position in the stacking area and return with the jack (hand-lift) or fork-lift truck to the car.

These steps as shown in the lower part of Fig. 14.26 will demonstrate that the 750 lugs of tomatoes were handled individually during the unloading in the car but only 16 trips (750 lugs ÷ 48 lugs per trip) were made to the storage point and return, while 16 skids were positioned in the storage area. Only 16 trips were made to the stacking area instead of the 107 trips made when the hand trucks were used and only 16 skid loads were positioned in the storage space rather than 750 individual handlings of the 750 lugs. A study of Fig. 14.26 will point out the considerable savings in handling operations resulting from the use of unit loads.

Some of the advantages of handling according to the unit-load principle are as follows:

(1) Unit loads reduce the number of individual rehandlings involved in stacking packages in storage areas.

(2) Unit loads reduce the number of trips required for moving packages into storage areas.

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(3) Unit loads simplify the taking of inventory, since the number of units multiplied by the number of packages in a unit gives the stock on hand.

(4) The use of pallets and fork-lift trucks increases storage capacity if loaded pallets can be stacked one on top of the other according to the height of headroom and the maximum floor load carrying capacity.

(5) Because of the reduced number of handlings, the amount of spoilage and deterioration resulting from broken or damaged packages will be greatly diminished.

Unit loads should be maintained until it is absolutely necessary for them to be broken up. The longer they can be kept intact for all handlings, the greater will be the possible benefits.

In selecting materials handling equipment, careful consideration must be given the particular requirements of the operations involved, the performance of certain types of equipment within the work area and with the facilities available, and the work load. Some of the more important items to be checked are the following: lifting requirements, stacking requirements, elevator capacities, floor load capacities, floor conditions, door heights and widths, freight car and motor truck working dimensions, area temperature, humidity and dust conditions, degree of slope of ramp inclines, aisle widths, distance of movement, and presence of gasoline fumes.

Mechanical equipment can obviously perform work much faster and with fewer men than manual methods. However, it is conceivable that because of the small volume of handling to be performed, the purchase of mechanical equipment cannot be justified. Also, when savings are small, it is not desirable to purchase new equipment unless there are other compensating advantages such as safer working conditions, better utilization of floor space, less damaged goods, and faster operations. Actually, the cost of performing the work can be increased by the use of the improper mechanical equipment. Where new equipment is needed, the simplest units suitable to the job should be selected. It is well to keep in mind that the more automatic the equipment used in materials handling, the greater the maintenance expense. Breakdowns can prove very costly if special parts are not readily available when needed for replacements. Nevertheless, it is obvious that the more operations or work that mechanical equipment can perform until its rated working capacity is reached, the lower the resulting materials handling costs will be.

Thus, equipment should be purchased for the savings that it makes possible in labor, supervision, and other aspects of operation for doing a stipulated amount of work. However, the decision to purchase should not be based on first cost alone. Most manufacturers of materials handling equipment have trained personnel ready to assist the potential user in working out his problems and requirements. In some instances, it may be wise to investigate the possibilities of renting equipment, a substantial portion of the rental investment to be applied later on the ultimate purchase of the equipment after its value as a permanent acquisition has been demonstrated. This makes it possible to ascertain whether the proper selection has been made as well as permit the development of actual operating costs. It should be pointed out that the annual maintenance cost can generally be estimated on this basis: 6 per cent of purchase cost on electric fork trucks; 10 per cent of purchase cost on gasoline fork trucks; and 4 per cent of purchase cost on powered hand transporters.

The speed of materials handling is increased, and costs are reduced, when materials are moved through the shortest distance possible from the unloading to the storage point and from the storage to the loading out point. Obviously, plant layout is an important factor in attaining maximum materials handling effectiveness. Some of the important considerations of physical layout have been mentioned above.

The results obtained with materials handling equipment are directly related to the familiarity of the worker with its use and application. Unless the equipment is properly operated and maintained, maximum savings will not be realized. Personnel must have thorough knowledge of its proper use to prevent accidents and to reduce damage to materials and products, as well as to obtain the maximum value of the equipment itself. While workers should be instructed in the use of new methods that have been developed for the equipment utilized, their own suggestions on improvements should not only be carefully considered but actively solicited because the constant use of the equipment by employees will suggest uses that otherwise might not be apparent. Properly instructed personnel will produce the following results:

(1) A decrease in the man-hour requirements of the involved materials handling operations.

(2) A decrease in the severity and frequency of accidents with resultant savings in compensation.

(3) Better handling and stacking.

(4) Reduced damage and repairs to equipment.

(5) Reduced damage to products and materials handled.

A thorough review of materials handling at regular intervals will be found essential to the maintenance of maximum operating efficiency. Different types of equipment will sometimes be found supplemental in solving materials handling problems. For example, when car and loading dock have different heights, it might be found advantageous to use a semi-live skid and jack within the car for loading packages onto a pallet; the loaded pallet on the semi-live skid can then be wheeled into position to be picked up by a fork-lift truck as illustrated in Fig. 14.27. Another utiliza-

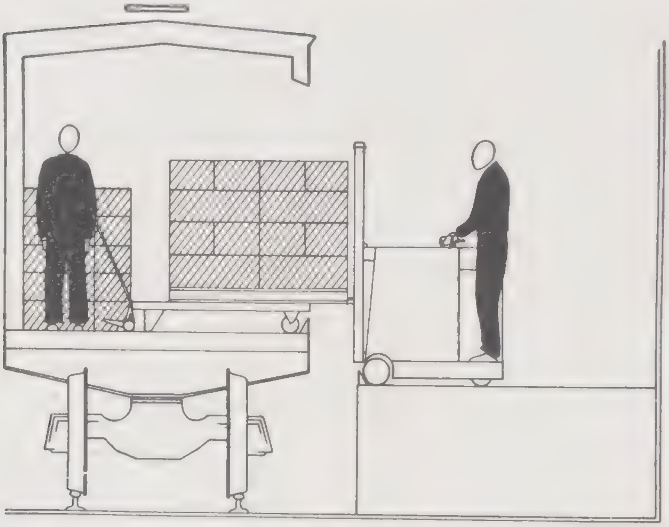

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FIG. 14.27. Loaded pallet on a semi-live skid about to be picked up by a fork-lift truck. Note overhanging of pallet over edge of semi-live skid.

tion of materials handling equipment might be a pallet dolly used in conjunction with a portable gravity roller-conveyor. A pallet dolly is a platform of proper size to hold a pallet. A series of rollers on the underside could carry the loaded dolly forward or backward along the floor of the car. The dolly is taken into the car and placed near the packages to be loaded. A pallet is placed on top of the dolly and loaded. After the load is complete, the dolly is pushed along the floor until it is in line with the conveyor section laid into the doorway (two conveyor sections laid side by side provide a steadier base for the pallet). The loaded pallet can then be pushed off the pallet dolly onto the conveyor section extending through the doorway, leaving the dolly for further use within the car and making the pallet available for the fork-lift truck on the loading dock (see Fig. 14.28).

It will be apparent that the combinations of use of various materials handling equipment, and even the improvising of auxiliary aids, can result in man-hour savings and enhance the facilities of many materials handling tasks. In the foregoing discussion, we have considered the basic principles which can be applied to many materials handling problems arising not only in the harvesting, transporting, and receiving of raw food materials but also in food preparation, processing, packaging, storing, and distributing. The details will differ in each case but the principles will still be found applicable.

Portable Handling Equipment for Solids

There are many different types of materials handling equipment because the raw foods, ingredients, supplies, and finished products vary so

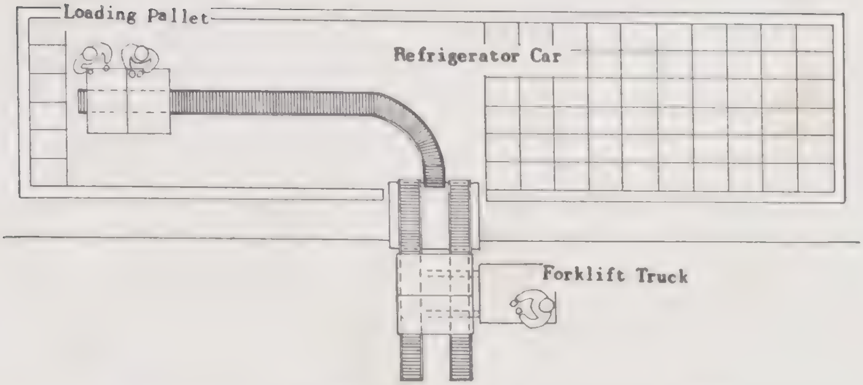

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FIG. 14.28. Full conveyor system with curved section allowing pallet to be loaded next to stored packages in car and moved to a position outside the car convenient for fork-lift truck handling.

greatly in physical condition. The incidental labor costs may be appreciably affected by this basic unit operation. Since foods to be processed or packed have either solid or liquid form or a combination of both, they can be moved either horizontally or vertically or along any inclined plane. Therefore, in order to present the various aspects systematically we shall first deal with the movement of solid materials.

In the movement of solid materials, there is constant need for portable transporting mechanisms. These usually include various types of hand trucks, power hand transporters, cranes, conveyors, skids, lift jacks, lift trucks, and pallets. The various types of portable materials handling equipment will be described briefly below, and are illustrated in Fig. 14.29.

The *pallet* is a unit upon which products packed or packaged in boxes, crates, barrels, drums, bags, cartons, etc. are loaded to permit their being picked up, transported, sorted, stored, or stacked in volumes that can be handled by mechanical equipment. Pallets are constructed in various sizes and of different materials such as wood, metal, plastic, or even corrugated paper.

Pallet containers are used for volume loads of loose materials, or for packaged materials, of uneven contour whose rigidity will not support superimposed loads. These units can be handled similarly to pallets.

Dead skids are used in a similar fashion to pallets but they are not ordinarily employed for stacking in storage. They are adaptable to freight car or truck loading and unloading, transporting, storing, etc.

Semi-live skids are used in freight car or truck loading or unloading, transporting, storing, etc., and are operated by means of lift jacks which raise the loaded skids sufficiently to permit their movement. One lift jack will ordinarily service 25 to 35 semi-live skids.

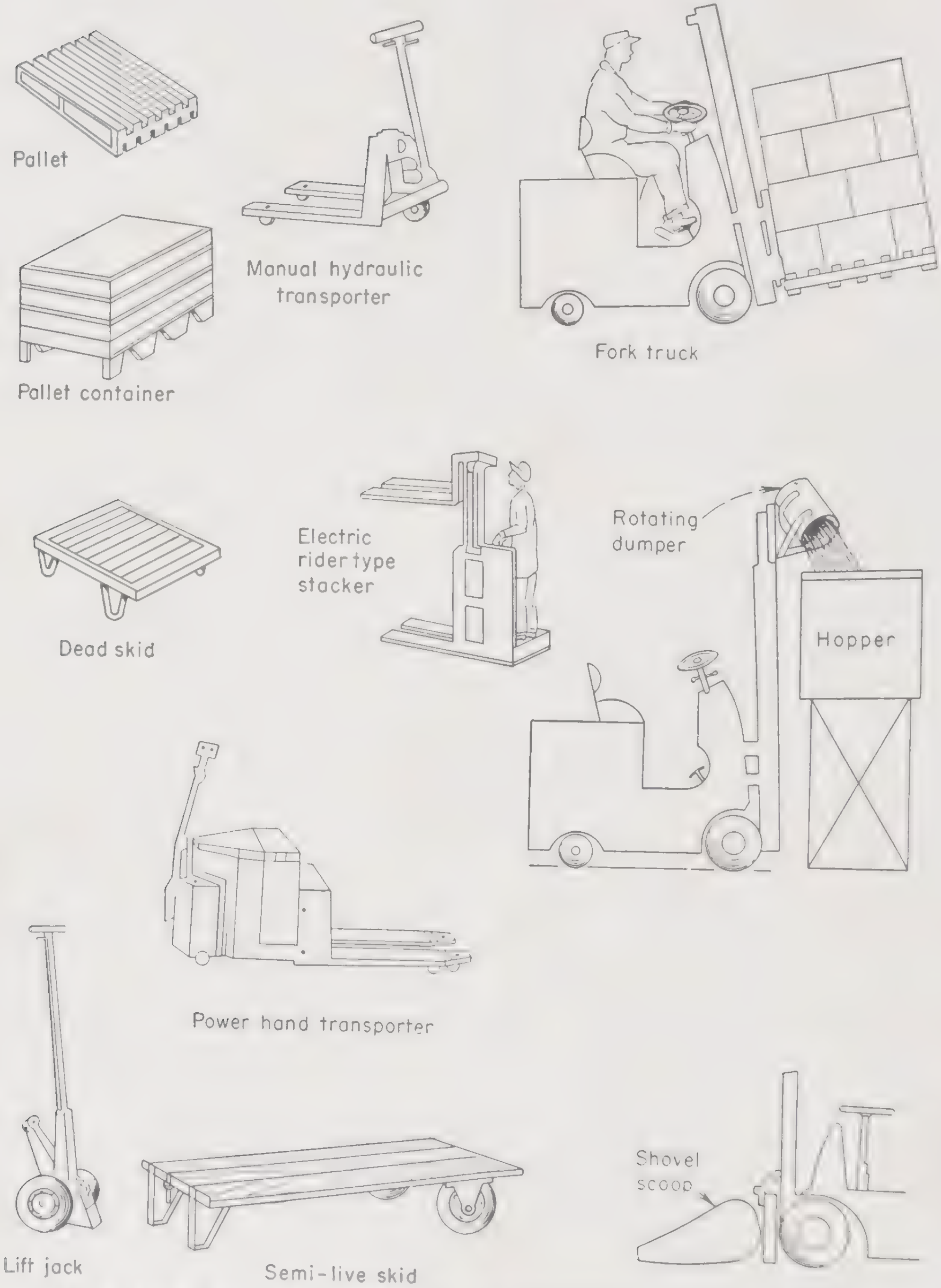

FIG. 14·29. Various types of portable materials handling equipment

Hand transporters are available in both powered and manually operated forms. They are used as transporters of pallet or dead skid loads and as such are adaptable to freight car or truck loading and unloading as well as the movement of loads in congested areas. Such equipment will normally handle loads of 500 pounds and more.

Lift trucks are gasoline- or electric-powered units that will mechanically pick up and transport pallet loads of materials weighing 1,000 pounds or more and stack them to heights up to 20 feet. In handling pallet loads, a lift truck is equipped with a fork-shaped mechanism that supports the pallet load; it is then known as a "fork truck." The weight of the fork truck itself is generally governed by the lifting weight required. For example, a fork truck required to lift 1,000-pound loads will weight approximately two tons whereas one required to lift 5,000 pounds will weigh approximately $4\frac{1}{2}$ tons. The equipment weight will vary depending upon the manufacturer's design.

Many different attachments are available to convert lift trucks into forms that will meet a variety of materials handling problems. For example, there are clamp arms for handling bales, barrels, drums, and vats; rotating heads for dumping barrels, drums, and vats; and scoops for shoveling and dumping free-flowing materials, as well as a variety of other attachments for special uses.

The cost of lift trucks depends on whether gasoline or electric power is used, the load capacity and the stacking height required, and the number of attachments and special handling accessories desired. While the initial cost of a gsoline-powered lift truck is much less than that of an electric-powered unit, the maintenance cost on gasoline-powered equipment is considerably higher and its use has to be confined to well-ventilated areas where the exhaust fumes will not taint food products.

Stacker type lift trucks are electric types usually employed where aisle space, elevator capacities and floor loads are limited. Normally, they are efficient transporters if the distances to be traveled are not over 250 feet but they will lift and stack pallet loads up to 4,000 pounds to heights up to 10 feet. Such trucks weigh approximately 2,000 pounds for stacking 1,000-pound loads and approximately 4,000 pounds for stacking 4,000-pound loads.

In the foregoing discussion of portable handling equipment we have not referred to the wheelbarrow or hand truck which is the simplest form of equipment for moving food products from one place to another. Actually, it is the least economical from the labor standpoint inasmuch as it permits the handling only of limited loads. About two cubic feet of material may be transported by one man using such equipment. Larger two-, three-, and four-wheeled barrows having a capacity of eight to nine cubic feet are sometimes used. Hand trucks with rocker pickup action and roller bearing wheels operating in the same direction facilitate the one-man handling of heavy drums and barrels. While there is still considerable use made of hand trucks and wheelbarrows, the more elaborate systems described in the foregoing discussion of portable handling equipment are gaining headway because of their more economical operational characteristics.

Fixed Handling Equipment for Solids

Fragility and perishability must be considered carefully in using equipment for moving all raw food materials. Consequently, it is often necessary that the mechanisms used in conveying food materials and products be subjected to intermittent or continuous treatments for the purpose of sanitizing their food contact surfaces. The possibility of quality impairment from materials handling sources has to be constantly guarded against. Some of the more obvious points of contamination will be noted in the discussion to follow, but if they are not mentioned in connection with a particular type of equipment, this is no indication that the possibility of quality impairment can be overlooked. Generally, such fixed equipment is concerned primarily with various types of conveyors and elevators.

Food materials that are being moved from one fixed point to another, continuously or intermittently, usually can be more economically handled by some type of permanent installation. When the materials must pass through a series of operations, gravity feed can oftentimes be used to advantage. In the ideal situation where the materials are conveyed to the top of a building or structure and passed down, from operation to operation, until removed as a product at the bottom, the only power requirement would be for the original elevation of the raw material. Food materials rarely permit of this ideal circumstance. Whereas in chemical engineering it is often possible to resort to the uses of chutes or slides, food engineers generally have to avoid using such devices because of abrasion and impact influences. Sluices are sometimes resorted to where water serves as a cushion as well as reduces friction between the food particle and the chute itself; such practice finds many applications in the fisheries industry. However, since chutes cannot generally be employed in food industries, extensive use is made of various types of mechanical conveyors.

Screw or helical flight conveyors consist of a metal shaft (stainless steel is preferred) having a spiral or helical fin fastened thereto and rotating in a trough without metal-to-metal contact, so that the helical fin pushes the material along the trough. Such conveyors are sometimes referred to as helicoid, spiral, or worm conveyors (see Fig. 14.30). The shaft is driven by motor through gears or a chain, the torsional stress usually limiting a single drive to about 100 feet although the shafts are usually in 10- to 12-foot

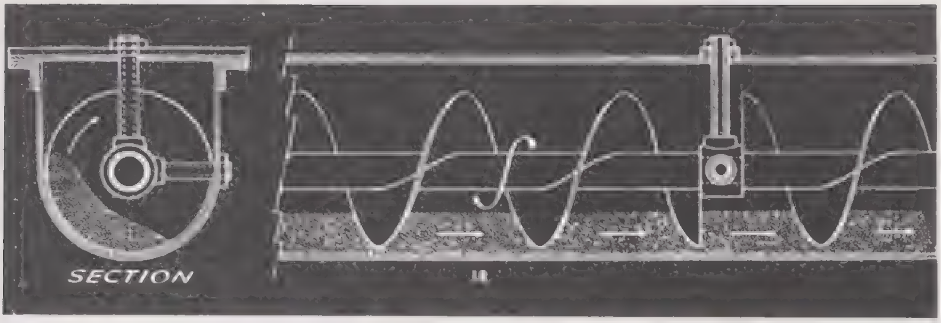

FIG. 14.30. The screw or helicoid conveyor.

sections. Screw conveyors are compact, requiring little headroom and no return mechanism. They are economical in original cost and maintenance. Materials are also mixed as they pass through such conveyors, and their tendency to crush friable materials, such as dried milk being stripped off a hot roller, may or may not be an advantage.

Screw conveyors are useful for transporting moderate quantities of material for moderate distances; over long distances, the drive should be located at the discharge and thus tend to pull the material along. If two sets of fins or flights are used, the inner flights are pitched in one direction while the outer ones are pitched in the opposite direction, in which case the conveyor becomes a mixer if no discharge is provided. If the trough is replaced with a screen, the unit can be operated as a sifter whereas if the screw is completely housed, it becomes an elevator. In case the screw is operated inside a steam-jacketed cylinder and under a vacuum, it becomes a rotary dryer or concentrator. It can easily be seen that the modifications which may be made of a screw conveyor make it adaptable to various unit operations such as materials handling, mixing, disintegrating, drying, etc.

The horsepower requirements of screw conveyors and of all conveyors operating with a scraping action may be estimated as the sum of the power to run the equipment alone, the power to overcome the friction of the material being moved, and the power to lift the material any vertical height. For screw conveyors the horsepower needed to run the equipment alone is essentially that required to overcome bearing and gear friction and is proportionately small. For horizontal movement, the total horsepower may be estimated as follows:

$$\text{hp} = \frac{(\text{Coefficient})\ (\text{Capacity, lb/min})\ (\text{Length, ft})}{33{,}000}$$

The coefficient for grain, for example, is 1.3.

Inasmuch as screw conveyors are generally used in moving dry food materials, they do not present too great a contaminating influence unless the products involved are hygroscopic. Care must be taken to use the proper metals in their construction so as to avoid metallic contaminations, however.

Flight conveyors and elevators consist of horizontal endless chains carrying vertical projections, called flights, shaped to fit a trough through which they push material along. The chains pull the flights and the material along the trough and pass over sprockets at the end of the run, one of the sprockets acting as the drive. This type of conveyor produces considerable wear on both the trough and on the product, the wear on the trough being reduced by attaching rollers to the flights.

Flight conveyors may be used on inclines up to 45 degrees although the incline preferably should be limited to 30 degrees. These conveyors are used widely for grain, food waste and garbage, and other relatively nonabrasive materials.

Belt conveyors, as the name implies, consist of endless belts looped over a drive or head pulley and an idler or tail pulley. Belts are made of canvas for boxes and packages; rubber-coated cotton web for especially hard usage; woven wire for spraying and drying operations in washing, blanching, canning, cooling, baking, quick freezing, etc.; and steel for grains and meats. Belt conveyors are adaptable to wide varieties and quantities of

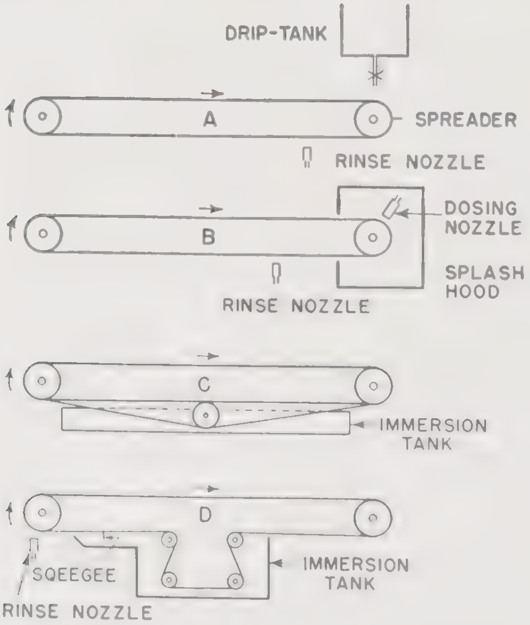

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Fig. 14.31. Various methods of sanitizing food-conveyor belts.

materials, require relatively low power, and can transport solid materials for long distances. The initial costs are usually higher than for other types of conveyors. Various methods of sanitizing belt conveyors are shown in Fig. 14.31.

The belt conveyor is one of the most efficient forms of materials handling along a horizontal plane although it can be used to elevate where the slope does not exceed a 20 degree angle. The capacity of the conveyor depends upon the width of the belt, its speed of travel, and its shape. When the rollers are troughed, the load can be increased two to three times its capacity when operated over flat rollers.

Power requirements for belt conveyors involve a number of variables. However, the horsepower required to drive belt and live load over rollers may be estimated by means of the following empirical formula:

$$\text{hp}^* = \frac{V(W_1 + W_2 + W_3 - R_2)}{660{,}000}$$

where

$R_1 = W_1 + W_2 + W_3 - R_2$,
W_1 = total weight of belt (lb),
W_2 = live load—total weight of material on belt (lb),
W_3 = total weight of all rollers including return idlers (lb),
R_2 = weight of belt and live load supported by slider bed (lb),
V = belt velocity (fpm).

The horsepower required to drive belt and live load over slider bed may be estimated by the following empirical formula:

$$\text{hp} = \frac{VR_2}{94{,}300}$$

The same general formulae apply to chain conveyors dependent upon whether the chains support the load or are assisted by slider guide rails.

Bucket elevators are used when the only direction of load movement is vertical. A common type of bucket elevator is illustrated in Fig. 14.32 and is generally referred to as the centrifugal-discharge bucket elevator. In the so-called "positive discharge" type, the buckets are sharply inverted as the chains pass over the head sprockets and then behind idler sprockets or wheels which snub the buckets and discharge the materials more forcefully than with the centrifugal-discharge type. The continuous discharge type of bucket elevator generally is built with the buckets so

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* Assuming ball bearing rollers and idlers; if sleeve bearing, multiply horsepower required to drive belt and live load over rollers by a factor of two.

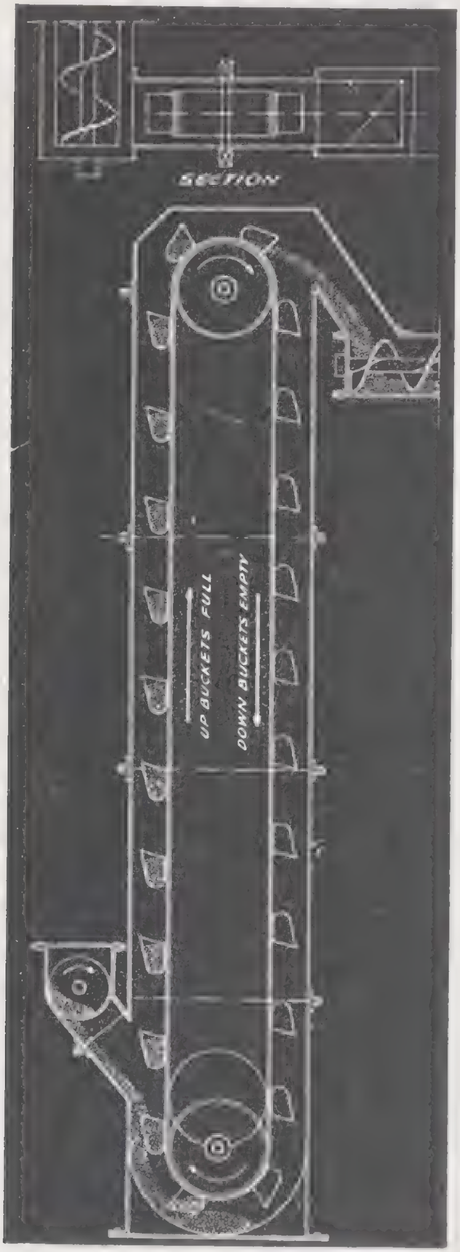

FIG. 14.32. Bucket elevator.

close together that each bucket discharges by gravity and with the load flowing over the front of the preceding basket into the discharge chute.

The power required for driving centrifugal-discharge bucket elevators may be estimated as follows:

$$\text{hp} = \frac{(\text{Gross turning effort})\ (\text{Speed, fpm})}{33{,}000}$$

The resistance to turning R_t in pounds at the pitch radius of the head or driving sprockets may be calculated as follows:

$$R_t = ML + C$$

where M = mass (lb) of material conveyed per foot of conveyor or elevator,
L = length of conveyor or elevator from head shaft to foot shaft (ft),
C = force (lb) required to drag the buckets through the material being loaded which value must be estimated or determined.

Other types of conveyors include drag conveyors, roller conveyors, pneumatic conveyors and elevators, vibrating feeders, compressed air systems, trolley systems, traveling cranes, skip hoists, and freight elevators.

Materials Handling of Liquid Foods

In discussing the unit operations of food engineering in Volume I, it was stated that pumping can be considered a type of materials handling. However, as pumping is essentially of fluid or gaseous materials handled by hydraulic or pressure means, in contrast to the handling of solid materials by gravity, either in their natural state or in containers having solid characteristics, it was considered feasible to separate them into two distinct unit operations. Further justification appears to be found in the nature of the mechanics involved in handling solids, gases, and liquids. Consequently, in this volume we shall treat pumping as a separate unit operation which shall be found discussed in essential detail in Chapter 20. Nevertheless, we shall discuss at this time some essential points in the materials handling of liquid foods concerning their conveyance in appropriate piping and collecting systems, leaving the discussion of pumping characteristics for later treatment.

The proper handling of liquid foods is a matter of great importance. They are very susceptible to spoilage influences in marked contrast to most fluid chemicals. Not only are microbiological contaminants of considerable concern, but their own enzymic systems plus minute amounts of metallic salts can prove extremely troublesome. The possibility of contamination by the metals and alloys used in the materials handling of liquid foods must be constantly guarded against. Copper and iron must usually be avoided in handling liquid foods, as only a few parts per million of either metal can render them unacceptable; even smaller amounts can cause serious nutritional impairments because of their adverse effects upon some of the critical vital factors such as vitamins. Antimony, cadmium, lead, and zinc should never be used in the construction of contact surfaces with liquid foods because of the possibility of toxicity. Among liquid foods, milk is one of the most delicate, being adversely affected by extremely small traces of copper, iron, or zinc.

The galvanic action that can be developed in liquid foods owing to the presence of dissimilar metals in the electrolyte supplied by the foods themselves can result in critical metallic contaminations. Furthermore, metallic salts can also be formed by the solvent action of liquid foods and their constituents upon the metal surfaces of pipes, fittings, pumps, vats, tanks, and other food-handling and food-processing equipment. These various products of chemical reaction between liquid foods and their metallic contact surfaces can either render the contaminated food unacceptable because of astringent or bitter tastes or impart nondescript off-flavors that subtly and adversely affect the palatability of the tainted liquid foods. It should also be pointed out that the salts of some metals are active oxidizers and catalysts whose presence in a food tends to induce complex biochemical changes including even the destruction of certain vitamins or the denaturation of certain essential amino acids.

Principles in the metallic construction as well as the sanitary design of food handling and processing equipment are now widely known and recognized by leading equipment manufacturers who have themselves contributed greatly to the advancement of food engineering. For that reason, high among the list of acceptable metals for the handling of liquid foods are the stainless steels, particularly the alloy commonly used in constructing dairy equipment containing 18 per cent chromium, 8 per cent nickel, and the balance low carbon steel. The high resistance of stainless steels to atmospheric corrosion is due to its protective coating of a continuous, self-perpetuating chromium oxide film. Chrome-nickel alloy, of which "Inconel" is representative, containing 13 per cent chromium, 80 per cent nickel, and 6 per cent iron, has been found equally as resistant to corrosion as the 18-8 stainless steels of which Allegheny metal, "Enduro KA 2," and "Rezistal KA 2" are good examples.

"Inconel" has the added advantage of superior ductility, lending itself better than stainless steel to the fabrication of helical coils, etc. However, tremendous strides have been made in the fabrication of all these metal alloys as they draw well, make good welds, are nearly insoluble in most liquid foods, clean easily, and are attractive in appearance. Stainless steel sheets are furnished in several degrees of polish or luster covering the range from a plain pickle finish to practically a mirror-like finish. The No. 4 finish is usually considered most desirable for a food contact surface in vats, tanks, etc., since it is very smooth, easily cleaned, and does not show scratches as does the higher luster finish, for example, the No. 7, which is practically a mirror finish. The 18-8 stainless steels cannot be used successfully in contact with brine as they are frequently corroded, small holes often appearing. Other metals and alloys are acceptable for a wide variety of liquid food uses although most of them lack the over-all advantages of stainless steels and similar alloys.

Solder is widely used in the fabrication and repair of food-handling equipment. Ordinary solder is half tin and half lead. There is also a satisfactory nontarnishing solder containing 95 per cent tin, as well as a suitable silver solder, both of which are innocuous in their contact with most foods.

Pipe and pipe fittings such as unions, tees, elbows, couplings, reducers, nipples, bushings, caps, valves, etc., are the age-old conveyors of liquids. Actually, pipe is used universally for conveying fluids and gases wherever their materials handling is necessary. Pipe in most food industries consists principally of two kinds: standard gas, water, or ammonia pipe; and so-called sanitary pipe.

Standard water pipe is generally made from wrought iron or mild steel, although some brass or copper pipe is used. Ammonia pipe is almost universally made of steel. The size of pipe usually refers to the approximate outside diameter. Small pipes are oversize; large pipe is less oversize, whereas twelve-inch pipe or larger is listed O.D. (outside diameter). The weight of pipe is characterized as standard, for common water and gas pipe; extra strong, for high-pressure steam or ammonia; and double extra strong for extremely high pressures. Conduit is a very light weight pipe, smooth on the inside, for housing electric wires. Extra strong and double extra strong pipe have the same outside diameters as standard pipe. The finish of pipe may be black for steam, gas, and ammonia; galvanized for water; or japanned for conduit. Pipe threads are usually made right hand, using Brigg's standard which is very similar to the U. S. standard and is cut on a taper of $1/16$ inch per inch, making it relatively easy to obtain a tight fit.

Pipe fittings are accessories for joining pipes and are usually made of cast iron for steam and ammonia, and of malleable iron for water. Fittings are either plain, beaded, or banded, depending upon the presence and amount of reinforcing material around the edges of the fittings. For all except the lightest work, either a beaded or banded fitting should be used. Sizes of fittings correspond to those of the pipe. Numerous types of standard and special fittings are available for different purposes and normally can be obtained from any reliable plumbing supply house. It is important that the fitting and the pipe be suitable for the service to be applied. Ammonia pipe and fittings are specially made, for example, and ordinary standard pipe and fittings should not be substituted under any circumstances.

Sanitary pipe and fittings are the liquid conveyors which were developed for, and used by, the dairy industry and are so constructed that they can be quickly and easily taken down for cleaning. Their cleaning is facilitated by their smooth finish inside and out. Originally, sanitary pipe was made of tinned copper tubing but now is available in various noncoated metals such as stainless steel and nickel, stainless steel being the most commonly used today. Fittings are made of so-called white metal (a nickel alloy) or stainless steel.

Sanitary pipe and fittings are made in standardized sizes and forms. Originally, the Dairy Industry Supply Association set up a standard of sizes based on the outside diameter, which still persists. However, the International Association of Milk Sanitarians, the U. S. Public Health Service, and the Dairy Industry Committee have since develop sanitary standards in the design of milk-handling equipment including piping and fittings which are known as the 3A Sanitary Standards program. In addition to these, standards or tentative standards have been similarly developed with respect to sanitary electric motors, pumps, tanks, vats, heat exchangers and similar processing equipment. As regards sanitary piping, the following standard sizes are used: 1 inch, 1½ inches, 2 inches, 2½ inches, 3 inches, and 4 inches, all measured O.D. (outside diameter). Based upon the flow with which the pipe friction head will not exceed 8 feet per 100 feet of straight smooth pipe, the recommended carrying capacities of the various sizes of sanitary pipe are as follows: 1 inch pipe, from 0 to 4,250 pounds per hour; 1½ inches, from 4,250 to 14,500 pounds per hour; 2 inches, from 14,500 to 33,400; 2½ inches, from 33,400 to 51,900; 3 inches, from 51,900 to 82,500; and 4 inches, greater than 82,500 pounds per hour.

Sanitary pipe and fittings, made up in standard sizes and shapes, conform to the set of standards based upon outside diameters set up originally by the Dairy Industry Supply Association and are still referred to as D.I.S.A. sizes although they have since been superseded by the 3A standards. The following standard sizes are used: 1 inch, 1½ inches, 2 inches, 2½ inches, 3 inches, and 4 inches, all measured O.D. (outside diameter). Their milk capacities have been determined and recorded by the Cherry Burrell Corporation, and are given below:

—	1 Inch	1½ Inch	2 Inch	2½ Inch	3 Inch	4 Inch
Pounds of milk per foot of length	0.285	0.689	1.23	1.97	2.89	5.26
Gallons of milk per foot of length	0.033	0.080	0.143	0.229	0.336	0.611
Volume per cubic foot of length	7.67	18.52	32.95	52.94	77.63	141.16

Friction heads for the D.I.S.A. standard sizes are given in Table 14.1

All sanitary fittings are designated by number, many special types being available upon special order. Fittings such as ells, tees, and valves are preferably threaded at all outlets with the nut and plain ferrule on the

TABLE 14.1. FRICTION HEAD*, FEET PER 100 FEET OF STANDARD SANITARY STAINLESS STEEL PIPE

Gallons per minute	Capacity (pounds per hour)	1 Inch	1½ Inch	2 Inch	2½ Inch	3 Inch	4 Inch
4	2,000	2.5					
6	3,000	5.5	1.0				
8	4,000	9.0	1.5				
10	5,000	14.0	2.0	0.5			
20	10,000	45.0	6.0	1.8			
30	15,000		12.0	2.5	1.0		
40	20,000		20.0	4.3	1.5		
50	25,000		30.0	6.0	2.3		
60	30,000		40.0	8.5	3.0	1.5	
80	40,000		70.0	14.0	5.5	2.2	
100	50,000		100.0	20.0	7.5	3.0	
120	60,000			29.0	10.5	4.3	
160	80,000			44.0	18.0	7.0	2.0
200	100,000			74.0	26.0	10.5	2.5
300	150,000						5.5

* If possible, a pipe size should be selected which will keep the friction under 8 feet per 100 feet of pipe. For more viscous liquids than milk such as ice cream mix, for example, the next larger size pipe should be used.

connecting pipe. A recessless-type fitting is now commonly used for the end of the pipe, the pipe projecting slightly through the ferrule before the fitting is soldered to it, and the end of the pipe and ferrule then being faced with a facing tool. Standard sanitary fittings are of either the ground-joint or gasket type. Inexpensive single service gaskets are used with both the ground-joint and gasket fittings. Hexagonal nuts are used for securing joints. A more recent development has been a fitting which replaces threaded joints, a clamp-like device holds the fittings and pipes securely together (see Fig. 14.33). All these various details represent advances in sanitary design which have developed through the combined experience of the interested industrial and regulatory agencies.

Considerable progress has been made in establishing the 3A standards for sanitary pipe and fittings as well as other sanitary equipment.[2] Following are some of the details concerning these standards.

A. *Material.* All 3A standard sanitary fittings shall be constructed throughout of dairy metal consisting of stainless steel, nickel alloy, or equally corrosion resistant material that is non-toxic and non-absorbent.
   1. All milk-contact surfaces shall be finished to an equivalent of not less than 120 grit finish properly applied.
   2. All outside surfaces must be smooth.

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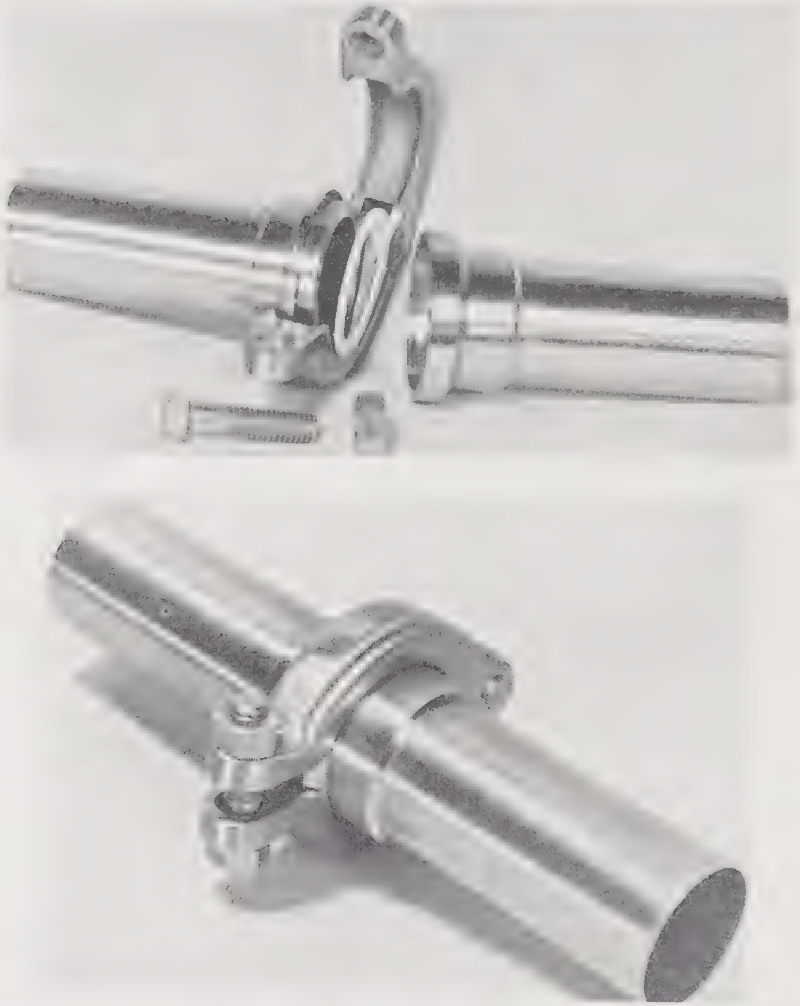
[2] These standards are published by the *Journal of Milk and Food Technology*, reprints of which are available from the Sanitary Standards Subcommittee, Dairy Industry Committee, Barr Building, Washington 6, D. C.



Courtesy Cherry Burrell Corp.

FIG. 14.33. Clamp type sanitary pipe fitting. Above, disassembled ferruled sections of sanitary tubing gasket with clamp, and bolt and nut for sealing the pipe ends without use of threaded connections. Below, fitting fully assembled.

B. *Construction.* These fittings shall conform to the specification of dimension, shown on the 3A standard drawing established for each fitting. The dimensions standardized either bear relationship to interchangeability or are necessary for reason of sanitary design.

C. *Gaskets.* Single service gaskets of the sanitary type, or removable rubber type gaskets that can be easily cleaned, shall be used with gasket type fittings.

D. *Tubing*

1. Tubing to be used with these fittings shall be constructed of dairy metal stainless steel, nickel alloy, or equally corrosion resistant material that is non-toxic and non-absorbent. The inside finish of such tubing shall be equivalent to, not less than, that of stainless steel tubing having 120 grit finish properly applied.
2. When stainless steel sanitary tubing is used it must conform to the American

> Society for Testing Materials *Standard Specification for Seamless and Welded Tubing*, #A-270-47, with the exception that the minimum 3A accepted inside finish shall be as described in paragraph D, (1).

In many food-processing plants, there are found successful installations of a special tough "Pyrex" glass sanitary pipe. Such glass piping is of interest for two main reasons: first, its transparency makes it possible to examine a product for defects during operation, as well as to determine the success of the cleaning operations, and second, it can be cleaned without dismantling, thereby saving considerable labor in clean-up time. It is not recommended for locations where it will be subject to great strain or where it must be dismantled frequently. It requires special fittings for joining and has to be installed with special care.

15. Separating

As was pointed out in Volume I, a study of the unit operations occurring in food engineering resulted in a list of fourteen major designations. It was further emphasized that there are a great many subdesignations in use, as each food industry has its own nomenclature. In fact, it was pointed out that the unit operation of *separating* had at least twenty-three or twenty-four commonly used subdesignations. Actually, one could argue that even the unit operations of *evaporating* and *drying* might be classed as subdesignations of *separating*, as in both of them water or other fluid constituents are separated from natural foods, the degree of water removal or separation being the only major distinction between these two unit operations. However, there are some fundamental physical distinctions that justify treating *evaporating* and *drying* as separate unit operations of food engineering, and these will be discussed later.

GRADING

One of the most important subdesignations of the unit operation of *separating* is grading (quality and size). Grading is obviously an essential unit operation in the assembly of raw materials in food production, preparation, processing, handling, and distribution. It is truly one of the most important factors in determining the final quality of any food whether it is the packed or the processed product of a natural food, or a formulation of natural foods.

Grading is primarily the separation of raw food materials according to size and quality at the time of their assembly and receipt for the purpose of establishing their commercial value. This assures greater uniformity of the finished products as well as greater economy in plant operations, because it permits the standardization of every important subsequent operation. More than that, grading often is the one operation in which ultimate profits or losses are established. Concurrently, it should be pointed out that too close grading can cause the cost of raw materials to rise, whereas too lax grading can reduce product quality and adversely affect acceptability. Obviously, the selection of the raw material used in the production of any food product is certain to influence its ultimate quality. Grading is an operation for which the individual producer or processor must set the standards aside from those that are established by law and regulated by federal, state, local, and unofficial agencies.

There is probably no article of commerce that is controlled, regulated, and supervised more than is human food. Incidentally, the supervision inherent in the multiplicity of governmental agencies at federal, state, and local levels is sometimes supplemented by that established by unofficial groups and trade organizations interested in the improvement of some particular food or class of foods. Ostensibly, governmental control is for the purposes of protecting the public health, improving sanitary quality, preventing fraud, minimizing competition, eliminating unfair trade practices, collecting revenue, and conducting research to solve problems of production, processing, preservation, transportation, and other aspects of food handling. Food grading, therefore, is intimately associated with food supervision and sometimes resolves itself merely into attesting conformities to grades set up by official supervisory agencies. However, it is also something distinct from food supervision. Food supervision as performed by governmental agencies is primarily for the purpose of assuring conformity to minimum standards of acceptability. Food grading, on the other hand, is usually concerned with quality control, which includes appeal, appearance, and acceptability, as well as cleanliness and nutritional value.

It is not the purpose of this chapter to deal in the complexities of quality control with reference to upgrading influences as well as to their consistent acceptabilities, important as such details are in any successful food processing and distributing enterprise. Rather, it is concerned with the objective methods applied, and particularly the means employed, to perform the incidental grading operations; in other words, the emphasis is on grading as a unit operation wherein economic influences are of primary concern.

Grading, therefore, deals not only with the commercial evaluation of the raw food materials being assembled for packing or processing but in its skillful exercise, it is also concerned with the predetermination of profit or loss in the subsequent processing or handling of the final food products themselves.

Grading Fruits and Vegetables

Grading of raw fruits and vegetables must begin with a choice of the best variety for the purpose intended, e.g., whether they are to be thermal processed, frozen, or dehydrated. Also, competition for markets has made the consuming public more and more flavor conscious with the result that the progressive food packer or processor will select, pack, or process and aggressively merchandise the varieties preferred by consumers.

In addition to choosing the proper variety, fruits and vegetables must also be picked at the proper stage of maturity. Unripe products lack flavor, color, and aroma characteristics of mature products, whereas those that are overripe become musty both in packing and in processing. Uniformity is obviously lacking if unripe, overripe, and properly matured fruits and vegetables are packed and processed together. Fruit for canning purposes is usually harvested when *firm ripe*, which is that condition of not being quite ripe enough for eating "as is" but of full size and with considerable flavor. *Canning ripe* is a condition well known to the grower as well as the processor and has come to have very definite meanings. Methods of testing the maturity of certain fruits and vegetables have already been mentioned in the discussion of harvesting details in Chapter 14.

Peas serve as an excellent example of the effect of maturity on quality. The proper variety of pea, carefully grown and harvested at the correct stage of maturity, will be deep green in color, higher in sugar, lower in starch, tender, and with a lower percentage of large sizes than if picked at a later time. To obtain maximum yields, the grower chooses to let the crop mature beyond the point preferred by the canner of high-quality merchandise, for example. In any given variety, the smaller size peas are the more desirable, hence grading for size is important. However, a much more significant quality grading technique is based upon the observation that fancy quality peas will float in a brine of 1.04 specific gravity whereas standards will float in a brine of 1.07 specific gravity. Peas which sink in a brine of the latter density are designated substandards or seconds. Large-scale mechanical graders have been developed which select peas by these physical differences and with important quality influences.

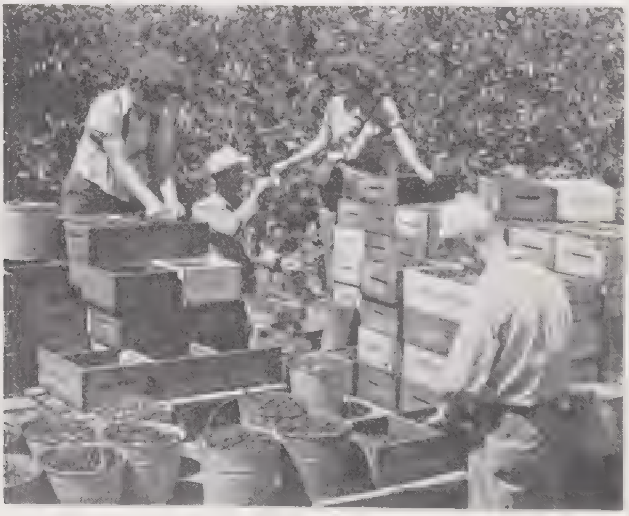
A very ingenious method of separating mature from immature cranberries is provided by dropping the berries on boards; the fully matured berries have less tendency to bounce and thus are segregated in compartments close to the board while the others are collected at greater distance from the board. The more modern devices are equipped with belt conveyors which permit continuous operation of this unique grading method. The berries are separated from the combings or rakings by running them through a fanning mill which blows out the leaves and other extraneous matter; this normally being considered a *cleaning* unit operation rather than a grading one.

In passing, it should be mentioned that a fancy product is normally one that can be secured only from the most nearly perfect stock grown in a given season. The trade recognizes (in the descending order of preference) fancy, choice, standard, and seconds for most fruits and vegetables. Carefully defined grade description have been developed for most fruits and vegetables by the U. S. Department of Agriculture in their regulation of trading grades.

Since the packer or the processor pays the grower on the basis of the amount and quality delivered, rough grading is done as soon as the fruits and vegetables are delivered to the plant. Oftentimes, field grading is performed with at least two purposes in mind: (1) to facilitate receipt and thus obtain premium prices and (2) to separate produce that is to be packed or processed. When the packing houses or the processing plants are in the vicinity of the orchards or fields being harvested, their checking of the grading in the field facilitates their receiving operations. Then too, the grower often finds it to his financial advantage to grade his harvest in the field and pay his pickers for their care in selecting and separating the crop as they harvest it. This practice is frequently resorted to in the harvest of fruit crops because of the necessity of repeated pickings, as all fruits do not mature simultaneously (see Fig. 15.1).

Overripe, undersized, and blemished raw materials are separated (graded) from those of recognized and acceptable quality. Corn, for example, must be sorted by hand on the basis of maturity; but engineering skill, spurred by the necessity of mechanizing for volume production at low cost, has introduced numerous semiautomatic graders mentioned in the discussion of harvesting. Grains, cherries, grapes, olives, oranges, and plums are typical examples of foods graded for size as the whole fruit or vegetable, while apricots, peaches, and pears are graded after cutting in half or halving and peeling. Pears are also in some cases graded for size mechanically before peeling or halving.

The grading of grains follows the general practice of grading lots at the time of sampling for the condition factors of temperature and odor, in-



Courtesy Michigan State College

FIG. 15.1. Field grading of red tart cherries. A picker is just receiving tickets for cherries being checked in. Girl, on the left and man on right are sorting

festation by live weevils, and any other noticeable qualities not requiring a detailed analysis. When samples are brought to the inspection office, dockage tests, weight-per-bushel tests and moisture tests are usually made first. Further analyses are made which are indicated as desirable or important by a careful examination of the sample. The various lots are then separated by binning them according to their qualities for milling or other processing.

Types of Grading Equipment

In the grading of fruits and vegetables various devices and types of apparatus are utilized to facilitate and mechanize grading operations.

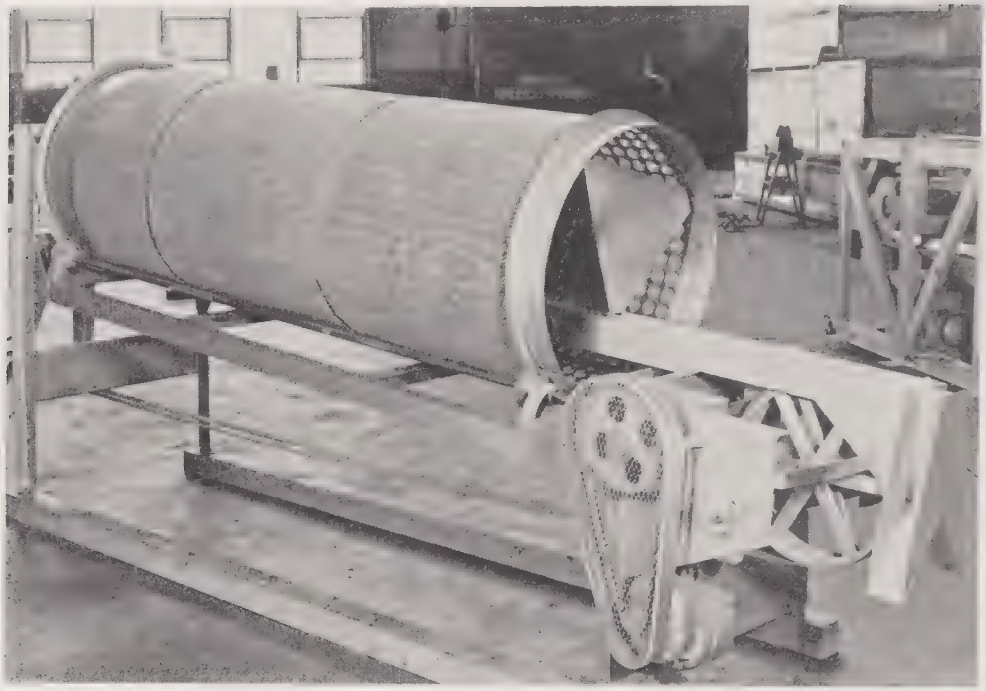
Flat screens consist generally of a frame with side panels and a screen bottom. They are equipped with a feed inlet and an arrangement for collecting the screened material. The screening is accomplished by imparting a motion by tapping, by shaking, by differential shaking (slow in one direction and rapid in the opposite direction), by electrical vibration (hummers), etc.

Most fruits and vegetables are graded over vibrating screens containing numerous holes of suitable sizes, a thirty-second of an inch generally being used as the unit variation in the diameter of these circular openings. This type grader usually has several interchangeable screens permitting use of the same machine for a variety of products. Whereas copper screens were formerly used, corrosion-resistant metals such as "Monel" and stainless steel are becoming more common.

In some models, the larger holes are at the top, thus segregating the larger product first and then discharging it over the end of the grader onto a belt conveyor. The smaller product is then successively graded and handled in a similar manner. In other models, the procedure is reversed although there is the objection that such tends to produce soft spots and bruises in the more delicately textured products.

Reels or revolving screens are generally horizontal, or nearly horizontal, cylindrical screens where the material enters at one end and falls through the openings into a collecting mechanism while the oversized material is discharged at the opposite end. Hexagonal and tapered hexagonal types are used preferably for the screening of fine materials, since these designs provide greater agitation. Fabric screens are generally used in flour manufacture, in wet and dry starch screening, etc., while perforated metal screens with various sized holes corresponding to different grades are generally used for peas, beans, and the like.

The conventional beet or pea sizer consists of a long, revolving clyinder with circular perforations which increase in size from the entering end to the opposite end.



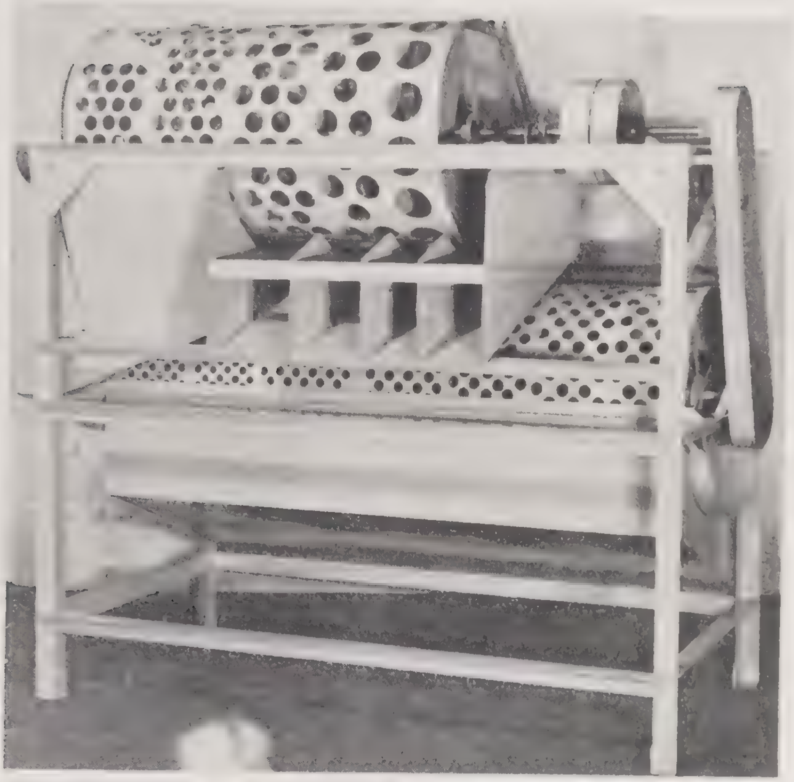
Courtesy Food Machinery & Chemical Corp.

Fig. 15.2. Cut string bean sizer.

A cut string bean sizer consists of a rotating cylindrical drum; the outer periphery is a screen that will retain the cut beans and the inner shell is a perforated cylinder, the diameter of the perforations being determined by the length of the cut bean which is to be separated from the beans being run. As the cut beans travel through the rotating drum, only those of a certain length will fall into the perforations and be retained by the surrounding screen; these fall onto conveyor belts as they reach the top of their rotary travel. The conveyor belts will receive only the separated cut beans of appropriate sizes from the sections of the sizer which they serve (see Fig. 15.2).

Another type of reel grader or sizer is the double beet grader which consists of two reels, one mounted above the other. The top reel receives the incoming assortment of beets and consists of perforated sides, the diameters of the perforations permitting the segregation and discharge of different sizes of larger beets and the passage of smaller beets into the bottom reel. This reel is also perforated for further separation and discharge of at least the smaller sizes. At opposite ends of both the top and the bottom reels are provisions for the discharge of oversizes (see Fig. 15.3).

Roller sizers consist of two hard wooden rollers, about 2 inches in diameter, mounted side by side, but closer together at the upper end (entrance) than at the lower (exit). The distance between rollers is adjustable. The rolls revolve away from each other and as the fruit passes along, the



Courtesy Joseph Wolfinger & Sons

FIG. 15.3. Double beet grader (rear view).

size of fruit dropping through progressively advances from smaller to larger. Appropriate sizes may be collected in receptacles placed below or diverted to individual conveyor belts. This kind of grader is highly recommended for spherical, unpeeled, or uncut products.

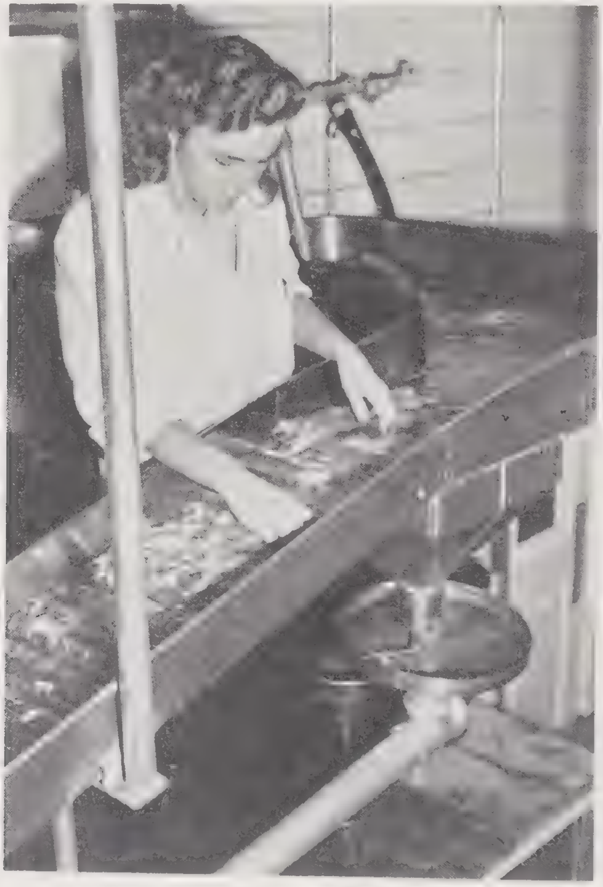
Cable, rope, or belt sizers consist of pairs of endless plain or rubber-coated ropes, steel cables, or belts traveling at an adjustable but diverging distance from each other so as to form a trough or V in which the produce is carried. As the belts, ropes, or cables travel away from the feed end the opening increases and the fruit gently drops through into canvas hoppers or onto belt conveyors.

The types of grading equipment just described are basically size graders. They do not segregate products on any demonstrable quality basis except insofar as size itself might reflect acceptability. Grading for quality has already been discussed in some detail with reference to experience evaluations by acceptability panels.

Grading Animals and Animal Products

Milk is, of course, subjected to a series of inspections, examinations, and tests which are utilized in its grading. However, aside from the equipment utilized in receiving milk supplies, the primary grading of milk is done by the operator who receives the shipments. In the case of individual transport can shipments, the usual practice is to check the temperature of the contained milk and to note the odor of the inside of the milk can lid where any off-flavors are quickly detected by an experienced operator. The actual grade of any particular supply is determined by the results of several laboratory tests which incidentally are the basis of the prices paid the milk producer for his supply.

The wholesomeness of most meat and meat products is insured by the federal meat-inspection service whereby numerous and rigorous types of regulatory inspections are conducted by the Bureau of Animal Industry. Inspections of cattle, sheep, swine, goats, and horses and of the food products derived from them take place at stockyards, slaughter houses, and food-processing plants. The grading of the animals is conducted by experi-



Courtesy Standard Oil Co. of New Jersey

FIG. 15.4. Oyster grading at Greenpoint, N. Y. Some oysters are shipped in the shell, others opened and canned. Here the opened oyster is being graded for size prior to washing and canning.

enced buyers who inspect the animals "on the hoof" which are kept segregated in various lots in paddocks of the stockyard. Veterinary supervision is provided at the public stockyards, where the animals are assembled for slaughter or reshipment. There is a federal law which is enforced by the Bureau of Animal Industry that prescribes a rest and watering period for animals being moved or held in transit for twenty-eight hours or more because of the effects upon the health of the animal. Most of the federal inspection and services and regulations, however, are applied to sanitary conditions of slaughtering and processing as well as to the inspection and certification of the carcasses. Aside from the segregations of the various lots of animals received at public and private stockyards, and the selection of animals by buyers for the meat packing houses, there are no other specific means of grading animals.

In the commercial method of determining the quality of eggs, the egg to be graded is held before a bright light in a dark room and its interior observed through the shell by a process termed "candling." The "candle" consists of the bright light mentioned above—a 40-watt electric light bulb is standard—enclosed in a metal case containing a hole just large enough to permit illumination of the whole egg. The light bulb is so placed that its long axis is at right angles to the egg when held blunt end up against the hole.

A person skilled in determining the condition of the interior of the egg by this method is known as a candler. He can grade from two to five cases of eggs per hour depending upon his experience and the accuracy of grading desired. The candler must translate what he sees within the illuminated egg into its appearance when broken out of the shell as the customer will see it eventually. Even the most expert candler will break an egg now and then to determine its condition out of the shell and thus add to his knowledge and experience. The most important condition that it is the candler's responsibility to identify is evidence of incubation. In addition there are many other types of deterioration classed as inedible which he also must recognize, as they detract from the acceptability of eggs as well as affect their grading.

In the grading of fish and shellfish for size and quality, rather wide use is made of water baths and sluices (see Fig. 15.4). Shellfish in interstate commerce are now under the supervision of the U. S. Public Health Service which inspects and rates a representative number of shucking and packing plants annually in each state, cooperates with the industry in making sanitary and bacteriological surveys, or by agreement, makes such surveys independently. In fact, the entire state control procedure and machinery are rated annually by the U. S. Public Health Service.

Section II

Preparation of Raw Materials

16. Cleaning

Cleaning, considered as a unit operation, is really a form of separation concerned with the removal of dirt, grease, insecticide, and fertilizer residue from foods and food containers as the first step in a processing program. The important problem of plant sanitation, i.e., the cleaning of equipment and plant, is a service operation and will not be treated in this volume.

The food processor has directed increasing attention to cleaning as a unit operation for several compelling reasons:

(1) Eye appeal. Food products presented for sale will not find a ready market, nor command a premium price, if not visibly clean and free of foreign materials.

(2) Rapid spoilage results when surface contamination is not removed.

(3) Insecticidal residues may be toxic and animal contamination may cause disease. Increasing use of uncooked foods and the growing popularity of frozen foods emphasize the necessity for adequate cleaning.

(4) Legal necessity. State and Federal food legislation, and many municipal codes, bear witness to the growing recognition of the importance of this subject.

Thus cleaning (as may be inferred from the above) includes all operations whose objective is the removal of all extraneous materials not suitable for human consumption. Major categories involved are such diverse operations as dry cleaning, washing with water, aerating (or aspirating), and filtering (or clarifying).

DRY CLEANING

Equipment engineers have approached the problem of cleaning America's huge annual grain crop with several objectives in mind. Corn, wheat, oats, barley, and similar grains commonly contain extraneous matter, such as insects, sand, hairs, rodent excreta, small stones, foreign seeds, and metallic particles. Obviously, it is not practical to harvest these cereals without such contaminating substances when one considers the normal channels of grain production with its many harvesting, transporting, and receiving operations.

Sifting

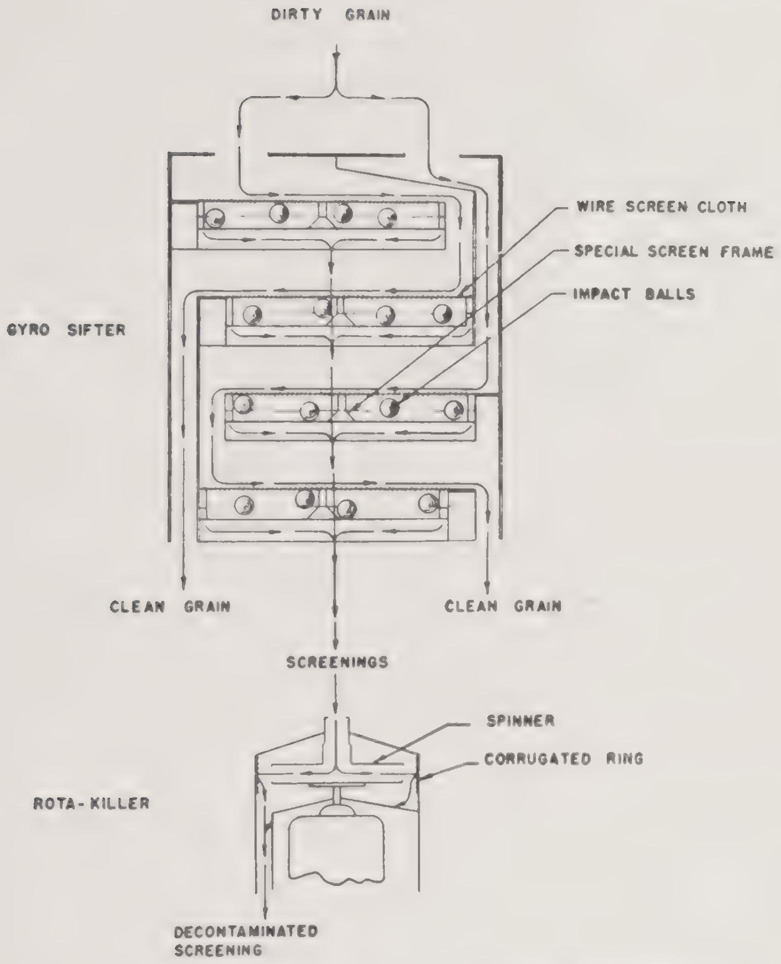
High-speed gyratory sifters have been designed to rapidly and economically remove grain contaminates, together with larvae and insect debris. This important cleaning operation prevents accompanying foreign matter from getting into terminal storage, and avoids the processing of grain which would contaminate the mill. The gyro-type of sifter has the additional advantage of not breaking the grain. In practice, if the sifter is operated ahead of the first break rolls, insect-free grain at the rolls is assured. One experimental run on 10,000 bushels of wheat (i.e., 500,000 to 600,000 pounds) which had passed through a series of cleaning machines removed 150 pounds of undesirable material (i.e., 300 to 400 parts per million), for example.

An additional advantage accruing from the use of the gyro-type sifter is its ability to remove the spores of black mold. Such spores at a moisture content of higher than 15 per cent can cause rapid spoilage of bran. Sifters of this type may be floor or ceiling mounted (see Fig. 16.1). Grain enters the inlet at the top of the sifter and passes over a series of sieves of such sized mesh openings as to hold the grain but permit extraneous matter to pass through. Large rubber balls keep the meshes open for long periods of time.

Screenings passing through the wire cloth go to an insect killing unit. One of the most successful methods developed for such purposes is a continuous treatment by the machine known commercially as the "Entoleter." This method utilizes centrifugal force, and the machine itself consists of a rotor formed by two circular horizontal steel plates. The lower plate is rigidly attached to the hubs fitted to the motor shaft, and the upper plate, with open center, is fastened to and separated from the lower plate by two concentric groups of round, solid, hardened steel spacers called impactors. These impactors are spaced apart around the outer and inner peripheries of the rotor. Grain, or flour, is fed into the center of the rotor (operated up to 3500 rpm) in a thin film by means of a distributor in the inlet and is then thrown by centrifugal force through the apertures formed by the two plates and the impactors. The treated product is discharged in a uniform spray around the rotor and is then carried off through the outlet spout. The particular value of the Entoleter (see Fig. 16.2) is its ability to kill all forms of insect life by such means.

Draper-Type Cleaning

To thoroughly remove loose dirt and aphis from a leafy vegetable, such as spinach, it is desirable to dry clean prior to wetting it in a flood-type washer. Such technique also removes small leaves and other refuse.



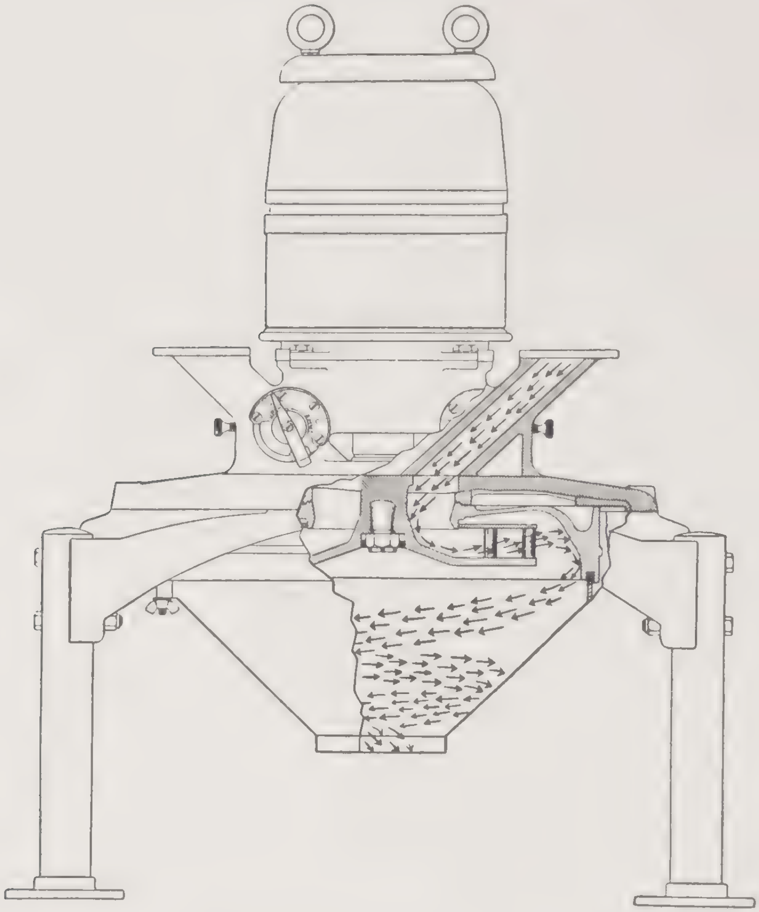
Courtesy Richmond Mfg. Co.

FIG. 16.1. Flow diagram of a gyro-sifter.

The product is carried through the machine (see Fig. 16.3) in a galvanized flat wire draper about 3 feet wide and 24 feet long. Two rotary forks loosen the spinach and spread it across the belt, fluffing it to get a more thorough cleaning. A shaking mechanism vibrates the draper, causing the dirt, aphis, and other refuse to fall through the mesh openings of the belt to a pan below. This spinach is now either carried on a conveyor to a sorting conveyor, or goes to a flood-type washer.

Magnetic Separating

This topic (and also the following one) might be considered under the unit operation *separating* but is discussed here with equal logic, for the removal of tramp iron from raw food materials is essentially a cleaning operation.



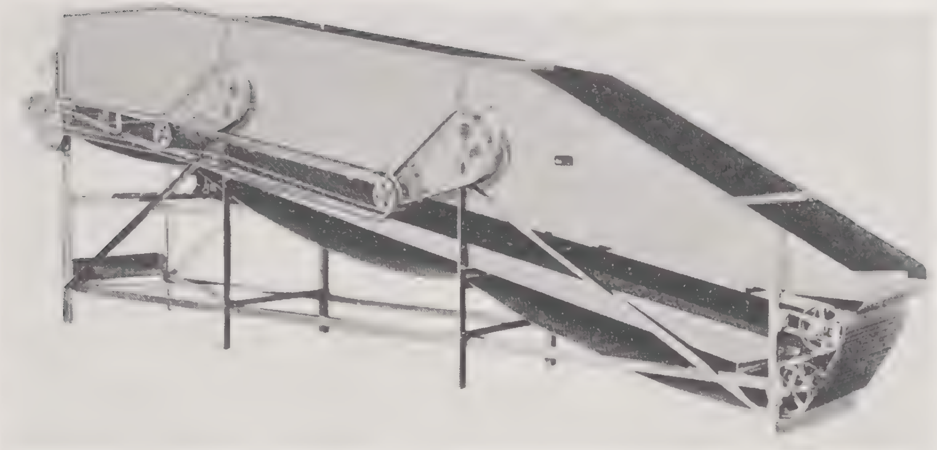
Courtesy Safety Car Heating & Lighting Co., Inc.

FIG. 16.2. Diagrammatic cross section of an Entoleter machine. The severe impact to which material is subjected as it passes through this machine destroys all forms of insect life.

Grain almost invariably contains small pieces of iron, such as nails, nuts, and screws. This material, if permitted to go into the milling system, can cause serious damage to the grinding equipment. In addition, tramp iron is a potential fire hazard since sparks resulting from metal-to-metal impact may cause a dust explosion. A magnetic separator, which separates magnetic particles from nonmagnetic grain, and discharges to a separate outlet, eliminates such danger.

Disc Separating

This technique utilizes the principle of length separation. Foreign seeds such as wild peas and cockles whose diameter approximates that of wheat kernels, obviously cannot be separated by screening techniques. But since these seeds are shorter than wheat, and such grains as barley and oats are longer than wheat, disc separation makes cleaning possible.



Courtesy Food Machinery & Chemical Corp.

FIG. 16.3. Spinach dry cleaner (Draper type).

The machine consists of a number of slotted discs with pockets large enough to pick out all the wheat from the longer grains, the latter being discharged to the front cutter. The longer grains are tailed out at the end. A second separator of the same design, but equipped with discs for the removal of all round seeds, eliminates those shorter than wheat.

WASHING (WET CLEANING)

In addition to the cleaning of unprocessed foods by sifting out the dirt, as well as the use of air currents to blow out lighter contaminants, extensive cleaning by washing with water is practiced.

The choice of water as a cleaning agent, both as a solvent and mechanical agent, is predicated upon certain unique properties. Water is:

(1) The most important solvent
(2) The most universally available liquid
(3) The most universally effective material
(4) The cheapest cleaning agent
(5) Free from undesirable residue.

Water of a quality suitable for the cleaning of foods must possess the following characteristics:

(1) It must be potable
(2) It must be free of bacteria
(3) It must be free of impurities, such as dissolved gases, and of solids that produce marked hardness.

Water and Water Treatment

Of the many considerations determining the location of a food-processing plant, none is more important than water supply.

All natural waters contain varying quantities of the materials with which they have come in contact, either in solution or suspension. Water, therefore, is not a pure liquid, but rather a very dilute aqueous solution of various substances. Since pure raw water cannot be obtained for industrial purposes, the fitness of any natural water for use in food processing depends upon its constituents.

Water to be used for cleaning foods must be potable, and to be acceptable in this respect, it must be free from suspended matter, color, odor, taste, bacteria, and poisonous chemicals, as well as contain a minimum of dissolved minerals. If satisfactory water cannot be supplied by a local government at a favorable rate, it will be necessary to use deep wells or river water, purifying as necessary. Supplies must be adequate at all times.

Chemical Qualities. Water containing two parts per million of iron is unpalatable to many people. This small amount spoils the flavor of tea and coffee, and combines with the tannin of spices to darken the product (catsup, chili sauce).

Four parts of hydrogen sulfide is unpleasant to the taste, and is corrosive.

Water containing 250 parts of chlorides per million tastes salty, and lesser amounts of chlorides are corrosive.

Calcium and magnesium salts produce hard water. Most vegetables are toughened when processed in hard water.

Purification of Water. Purification of water is the removal or reduction in amount of substances that render waters in their raw state unsuitable for use. It is practiced on a large scale with one or more of these objectives:

(1) To render the supply safe and unobjectionable for drinking and food treatment

(2) To reduce the amount of the mineral ingredients (important in hard water areas)

(3) To remove substances injurious to equipment or the manufactured product

Removal of bacteria, turbidity, odor, taste, and iron are the principal requirements under point 1. The common methods of affecting such purification are slow filtration through sand, rapid filtration after coagulation, or both methods combined with natural or induced sedimentation.

Slow sand filtration consists in causing the water to pass down through a layer of sand of such thickness and fineness that the requisite removal of suspended substances is accomplished. The efficiency of the filter is measured by the ratio between the number of bacteria in the raw water and the number in the effluent, and should exceed 99 per cent.

The filter is usually a water-tight concrete basin with tiles on the bottom laid in the form of a grid. On top is a layer of gravel approximately a foot deep, graded from 3 to 25 mm in diameter from top to bottom. This will support a layer of fine sand three to four feet in depth. When water is applied to the surface, it will pass through the sand and gravel and flow away through the drain tiles. Suspended solids, including bacteria, are removed by the sand, the action of which is rendered more efficient by the rapid formation of a mat of finely divided sediment on the surface. When the film becomes so thick it retards filtration unduly, the water is allowed to subside below the surface and a half inch of sand is removed; filtration is then resumed. The removed sand is washed free of impurities and replaced on the bed after successive scrapings have lowered the bed about a foot. To avoid interruptions from service, it is necessary to have several filter beds. These are usually roofed and sodded. Iron is removed by aeration, carbonic acid being evolved and oxygen absorbed. The iron precipitates and can be removed by filtration.

Rapid sand filtration consists of running raw water into a basin and treating it with a coagulant, usually aluminum sulfate. The gelatinous precipitate of aluminum hydroxide formed occludes the suspended material as it drops to the bottom and adsorbs the organic coloring matter. Formation of such aluminum hydroxide depends upon the natural alkalinity of the water, lime or soda ash being added when necessary. The treated water is allowed to stand 3 to 4 hours to permit the sediment to settle. It is then passed rapidly through a sand and gravel bed to remove the balance of the suspended matter.

Disinfection is usually accomplished by the addition of chlorine. This is not a substitute for purification by filtration but an adjunct.

Water Softening

This is accomplished by treating the water with the proper predetermined amount of precipitant, allowing it to settle, and drawing off the water.

In recent years, zeolites have been used to soften water. An ideal zeolite would have the formula $Na_2O \cdot Al_2O_3\ (SiO)_2 \cdot 6H_2O$. When water containing magnesium and calcium sulfates or bicarbonates is passed through a bed of zeolites, the sodium ion in the zeolite is replaced by calcium or magnesium with the result that sodium sulfates or carbonates have been exchanged for the calcium or magnesium salts in the original water. These sodium salts do not form scale and do not toughen food products. To regenerate the zeolites, a 10 per cent solution of common salt is passed through the bed, reforming the sodium zeolite and discharging exchanged magnesium and calcium chlorides in the effluent from the softener. More recently ion exchange resins have been introduced.

The cleaning properties of water can be improved by the use of physical, mechanical, or chemical aids, as follows:

Physical and mechanical Aids

(1) Heating
(2) Containers for soaking
(3) Flushing, such as water under pressure
(4) Abrasion, such as scrapers, brushes
(5) Screens and filters for separation
(6) Moving aids, such as elevators, conveyors, etc.
(7) Drying aids, such as centrifugals, fans, etc.

Chemical Aids

(1) Water softeners
(2) Acids
    (a) HCl to remove spray residues from fruit
    (b) Gluconic acid for water softening,
(3) Alkalies to emulsify fats and peptize various forms of soil
(4) Synthetic detergents or surface-active agents to increase wettability and general cleansing action

The final selection of the chemical aid to be used depends upon its suitability for the purpose intended; its cost; and legal restrictions.

Cleaning of Bottles

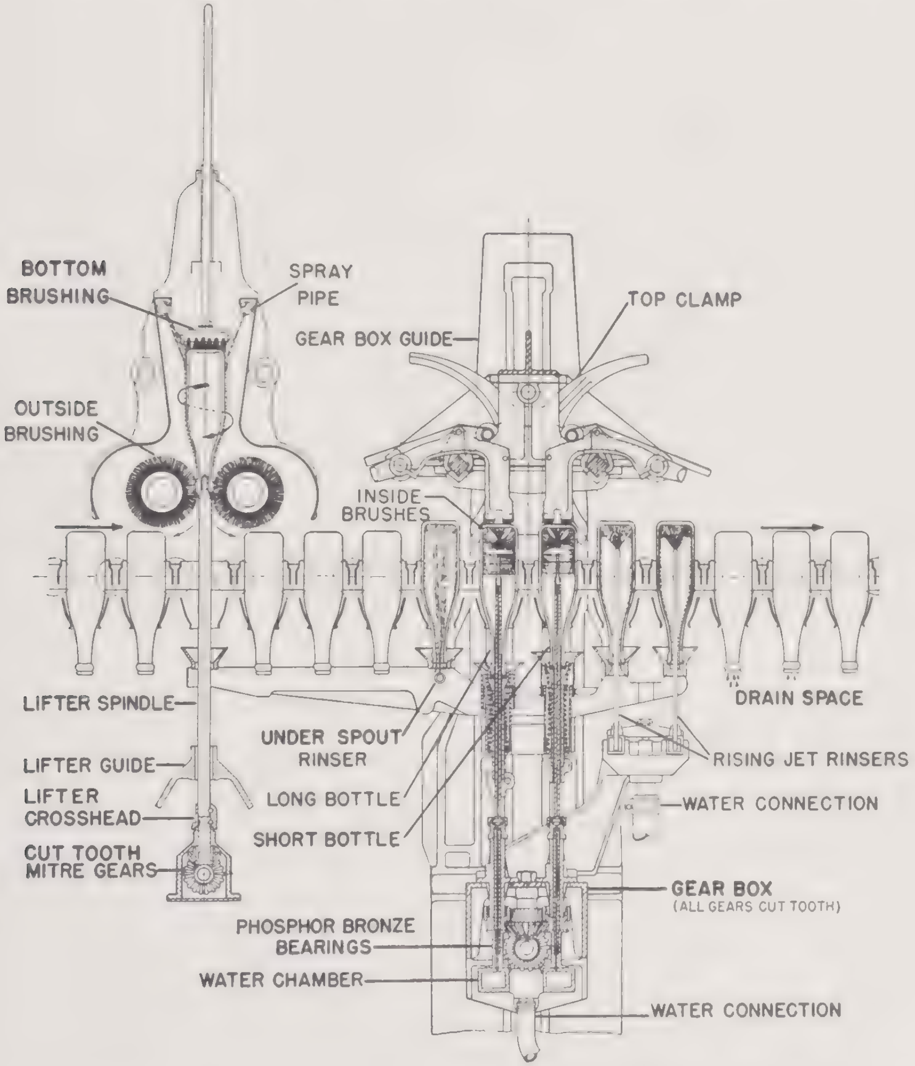
To the uninitiated, the washing of glass containers for refilling is a simple step. Actually the operation requires close attention to details in order to secure the degree of cleanliness necessary in merchandising a beverage. The container must be free from both visible and invisible contamination, possess a lustrous surface, and contain no residual cleaning compound; also it should not cause a change in odor or stability of the packaged product.

The problem is substantially identical whether the container is intended for milk, beer, or carbonated beverages. The cleaning compound, to meet the requirements enumerated, must combat hardness in water, saponify grease, remove deposits, destroy microorganisms, wet and remove labels, and be free rinsing. Health authorities having jurisdiction should be consulted for standards of performance before any compound is ordered.

Sodium hydroxide has been generally accepted as the most effective and economical cleaning chemical. Proper formulation for bottle washing, either in bath or spray machines, should involve not less than a total of 3 per cent active alkalinity at 135°F, plus some polyphosphate or gluconic acid in hard water areas, and possibly a small amount of synthetic detergent to enhance bactericidal action, secure rapid penetration of labels, and reduce surface tension to promote maximum rinse, with minimum chemical carry over or water spotting. If foaming becomes a problem that cannot be controlled mechanically, the addition of small amounts of calcium chloride or other suitable foam inhibitor will generally correct the situation.

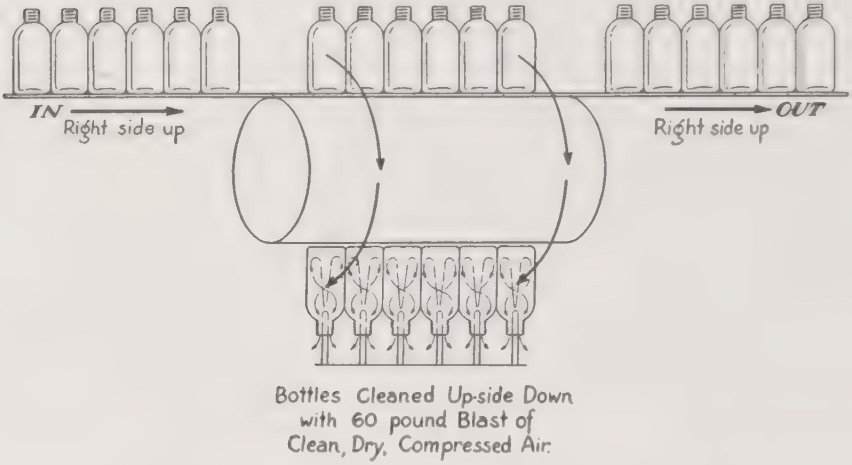
The soaker-type washer is widely used in the cleaning of glass containers. Such machines consist of an endless chain of pockets arranged in rows. These pockets hold the bottles upright as they pass through the cleaning solution but invert them for the rinsing operations, which involve brushing and spraying to loosen and discharge foreign materials (see Fig. 16.4A).

In addition to the soaker-type washer for cleaning glass containers, available equipment includes rinsing machines and air cleaners. These find application only for the cleaning of new glass or single-trip containers which do not require sanitizing at the point of filling. These machines remove any dust, carton lint, glass chips, or other foreign material that may



Courtesy George J. Meyer Mfg. Co.

FIG. 16.4A. Brushing and rinsing operations of an automatic bottle cleaner.


IN
Right side up
OUT
Right side up
Bottles Cleaned Up-side Down with 60 pound Blast of Clean, Dry, Compressed Air.

Courtesy Pneumatic Scale Corp., Ltd.

FIG. 16.4B. Flow sheet depicting inversion and air cleaning of bottles.

have entered the container between the time of its manufacture and its use in the packaging plant (see Fig. 16.4B).

Bottle rinsers utilize sprays of water to rinse both the inside and outside of the inverted containers (i.e., inverted at the time of their rinsing as they are fed to, and discharged by, the rinsing machine in an upright position). The rinse water may be heated as well as included sanitizing solutions.

Air cleaning appears to be replacing rinsing of new glass or single-trip containers. This may be justifiable for new glass containers received in a sanitary condition. Certain filling machines are being equipped with built-in air cleaners. With multi-trip glass containers, however, such as are used in the dairy, brewing, and carbonated-beverage industries, thorough soaking, rinsing, and sanitizing are provided in machines designed for such purposes as have been discussed and described above.

Washing of Cans

Many packers of food in cans wash the container prior to filling to eliminate dust accumulated during shipment and storage. This cleaning operation also improves the appearance of the can, and eliminates oil and grease, particularly important in meat and fish packing. A detergent in the wash water is generally indicated.

For the washing of lithographed beer cans of one size, a rotary machine has been developed. The cans roll by gravity into the washer and fall into a pocket to a star wheel. As the can is carried through the machine it is thoroughly cleaned, and since it travels horizontally at a slight angle, complete drainage occurs. Each can receives an individual spray of either cold or hot water, or steam. Other rotary washers are available for a variety of can sizes.

A somewhat simpler type washer, complying with legal requirements, has been so designed that no can passes through the machine without being washed. With the starting and stopping of the machine, the sprays start and stop automatically. This provides good performance with a saving of water. The cans enter the washer in a horizontal position but are turned into a vertical position directly over sprays of hot water. Thorough washing and draining are thus assured. The cans then pass over steam jets to sterilize and dry, following which they are turned back to a horizontal position to facilitate rolling to the point of use.

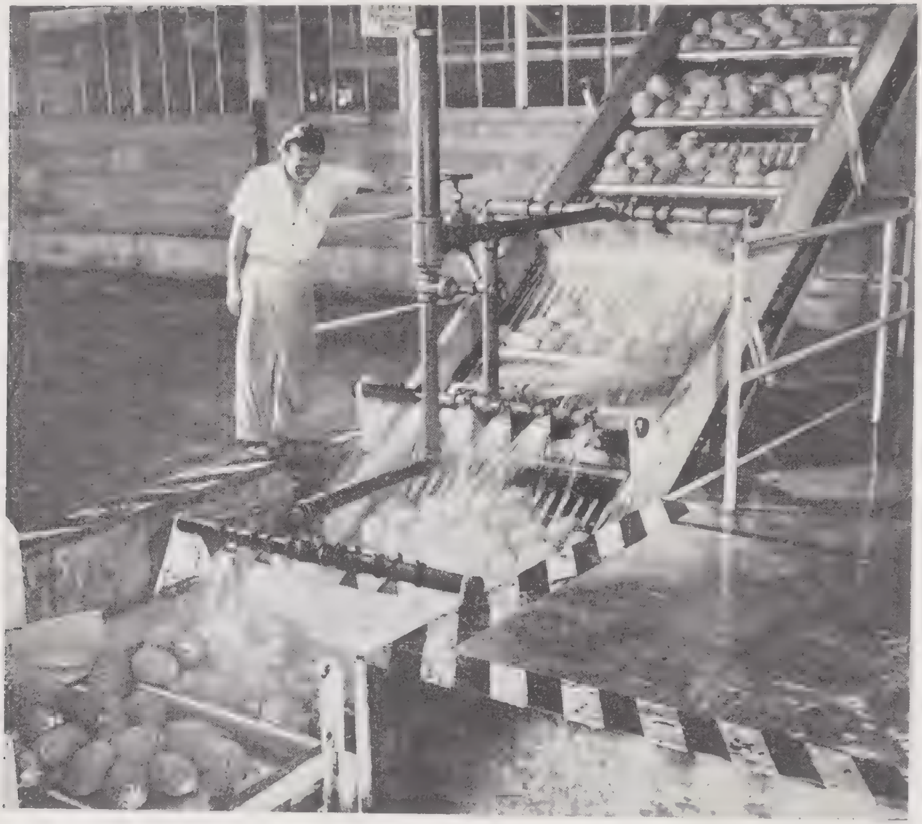
Washing of Vegetables and Fruits

The washing of fruits and vegetables with water is accomplished in three ways: soaking, agitating, and spraying. In considering the design of suitable washing equipment, the engineer must keep in mind the nature of the product to be treated, the need for maximum dirt removal with minimum water consumption, avoidance of injury to the product, and rate of output.

Soaking to loosen adhering dirt and soften sticky coatings is an excellent preliminary step to washing by agitation and spraying. Under no circumstances should soaking alone be considered an adequate washing technique. Water at elevated temperatures (115 to 125°F) is more effective as a soaking agent than cold water. The supply of water must be ample, and the soaking vat must be emptied and refilled with clean water at frequent intervals; otherwise it may serve as a source of contamination rather than as a cleaning solution.

Agitating the product and/or the water greatly increases the effectiveness of the washing process. Adhering dirt is obviously more readily removed when the product is agitated during the cleaning process and oftentimes merely agitating the water surrounding the product will expedite any dirt removal.

Of the various methods of washing, spraying by water is the most highly regarded. Very dirty products should be given a preliminary soaking to loosen adhering contaminating materials. The effectiveness of a spray is dependent upon several factors. The nozzle should be designed with respect to the volume and pressure of water used and the fineness of the spray itself. It should also be adjustable for distance from the product and angle of impingement. Too little attention has been given these important details in the design of spray washing machines. A large volume of water under low pressure (15 psi) is not as effective as a smaller volume of water delivered at higher pressures (40 to 60 psi). Also, an effective spray must strike all parts of the products being cleaned. This is accomplished in various ways, such as positioning sprays above and below traveling woven-



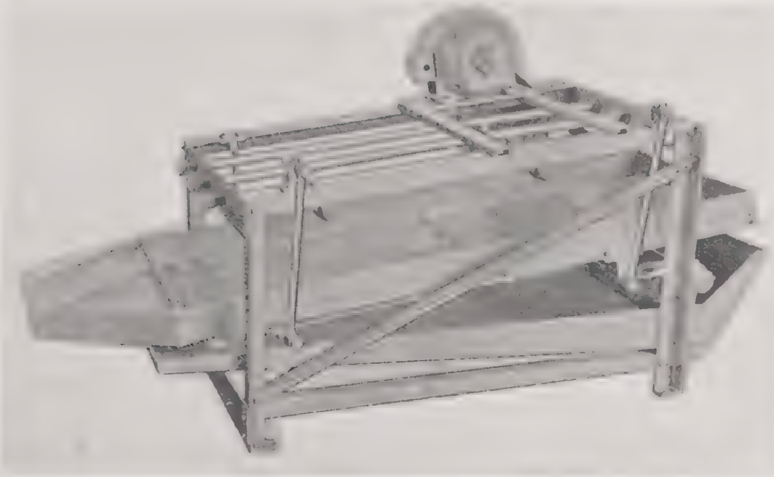
Courtesy Libby, McNeill & Libby

FIG. 16.5. Spray washing of pineapples. Positional sprays aided by flight conveyor provide for exposure of all parts of fruit to high-pressure hydraulic scrubbing.

wire conveyor belts or flight elevators (see Fig. 16.5), or by rolling the product down a slightly inclined rotating perforated cylinder.

During periods of peak production there is a tendency to overload washers, resulting in dirty products getting into the production line. Those in charge of plant operations must be aware that the effectiveness of washers depends upon the speed with which the product passes through the units, the amount and temperature of water used, effectiveness of the sprays, and amount of product. When washers are overloaded, the products being cleaned do not receive the full force of any sprays, as they act as baffles one to the other. It is folly to spend careful efforts in designing an effective washer and then present it with a situation (such as overloading) for which it was not designed.

Pre-Washing. Root vegetables, particulary if fibrous and grown in nonsandy soil, may have considerable adhering soil, especially if it has dried on the product. Equipment permitting soaking and prewashing is helpful. It consists essentially of a water bath and draper elevator. The water cushions the fall of the incoming product. An inclined elevator lifts



Courtesy Food Machinery & Chemical Corp.

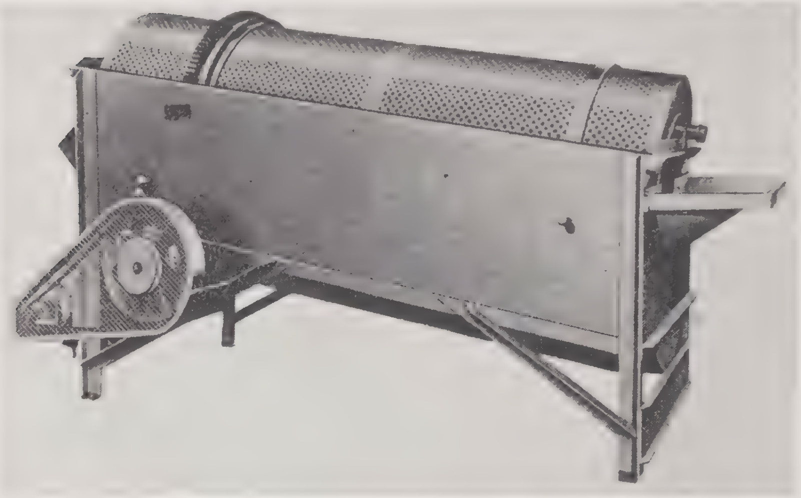
FIG. 16.6. Shaker washer, motor,driven.

the product from the water and carries it under a series of sprays mounted directly above the draper, thus giving the fruit or vegetable a final wash. The draper is usually a ½ by 1 inch galvanized flat mesh with metal flights attached.

Shaker Washing. Shaker washers are designed primarily for washing green peas, whole kernel corn, beans, etc. (see Fig. 16.6). The screen is moved rapidly forward and backward by eccentrics, water sprays playing on the product as it spreads out thinly over the screen. Splits, skins, dirt, and other refuse is washed through the slots. The size of the perforations can be varied, depending on the product to be handled; also, different eccentrics are required—whole kernel corn and green beans require vigorous shaking by a 3-inch eccentric while peas require less agitation, a 1½-inch eccentric being satisfactory.

Washing Leafy Vegetables. A revolving cylinder of wire mesh or perforated sheet within which are mounted four longitudinal flights formed of pressed steel with a sloping base on the forward side, constitutes the essential design of a leafy vegetable washer (see Fig. 16.7). The product is carried up the revolving cylinder wall just far enough to turn it over as it rolls down; thus turning the vegetables over and over while being exposed to a spray of water. The dirty water passes through the cylinder wall openings to a drain beneath. The cylinders are from 3 to 3½ feet in diameter, and about 21 feet long. This type is commonly used for washing spinach but is not too efficient as it tends to roll the vegetable into "balls."

Flood Washing. The product to be cleaned is gently driven along through tanks from 17 to 36 feet long by the action of a series of low-pressure sprays. Floating the leaves in a fanned-out condition makes it easy to remove



Courtesy Food Machinery & Chemical Corp.
FIG. 16.7. Cylinder washer.

particles of sand and other foreign matter. This soiling material sinks through a false bottom of screens which prevent recontamination. A 3 by 17 foot washer will handle from 2 to 4 tons of spinach per hour.

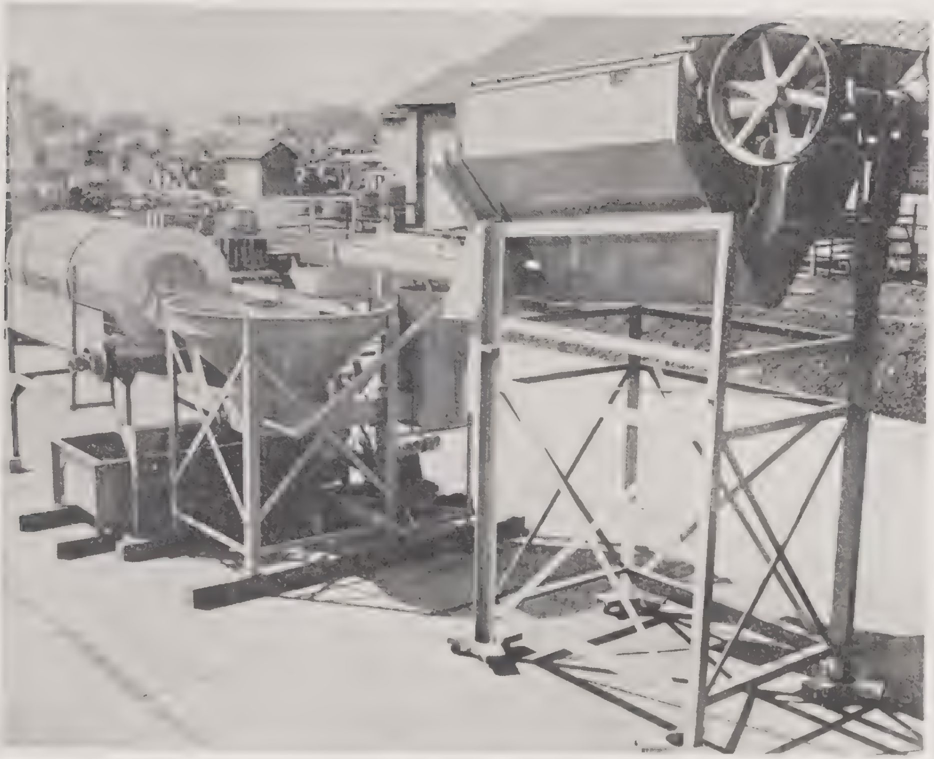
Corn Washing. Canned corn is a favorite in America, and the size of the pack justifies special consideration of equipment needed to handle it.

One type of popular corn washer is a heavy duty, large capacity, all metal machine which gently tumbles, rubs, and scrubs the ears, one against the other, loosening the dirt and flushing it away with water sprays. By installing in the lines immediately after husking, and before sorting and trimming, it greatly reduces the work of the sorters and trimmers. The cone-shaped construction of the corn washer causes the corn to travel faster all the time, avoiding blocking and resulting in a capacity of 50,000 No. 2 cans per day.

Another popular machine is the Whirlpool Washer (see Fig. 16.8). Cleaning is by flotation and spraying. Strong currents of water bring the washed corn out of the bottom of the flotation tank, no mechanical devices being used which might damage the corn.

Grain Washing. It was recognized long ago that certain types of surface dirt, and dirt deposited in the crease of the wheat berry, could be removed only by washing. Furthermore, wheat harvested by certain outmoded methods comes to the mill contaminated with mud balls that only water will remove. Obviously such wheat will also contain small stones.

A combination washer and stoner has been developed to meet this situation. The wheat fed into the stoner is carried by water into the washer. All material with a higher specific gravity than water will settle out. The washer completes the cleaning started in the stoner. Excess water is re-



Courtesy Food Machinery & Chemical Corp.

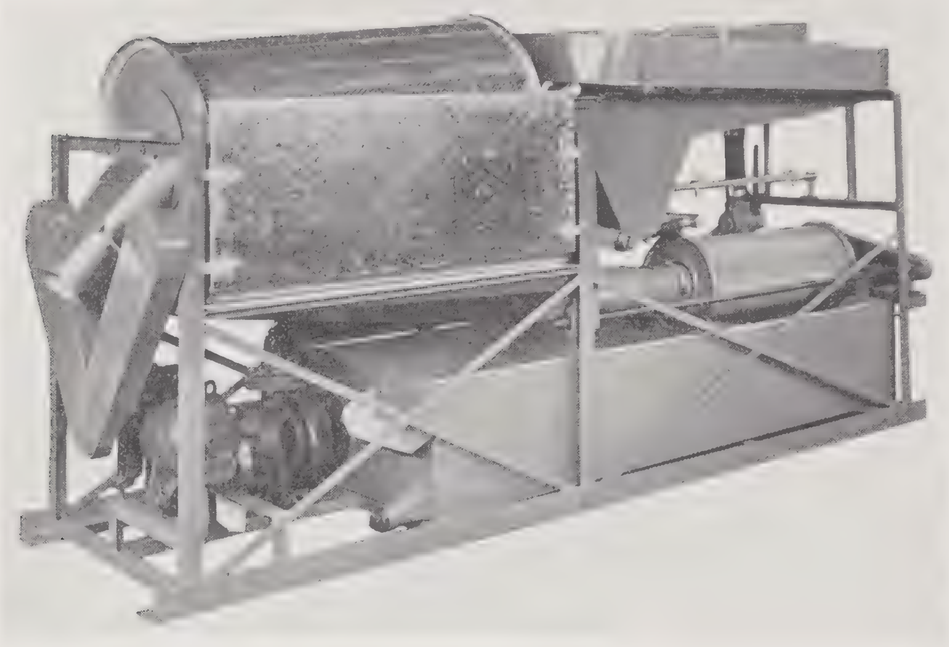
FIG. 16.8. Lewis Whirlpool Washer. At right; a double cob reel on high legs discharges by flume into the washer, which in turn passes the corn on to the rotary washer at left.

moved and the washed wheat is lifted by bucket elevators to a screw conveyor mounted on the top of tempering bins.

Fruit and Berry Washing. Because of their soft, delicate texture, foods falling into this category require special handling. Yet adequate washing is essential if dirt and sand are to be removed from products growing near the ground, such as strawberries.

The fruit is emptied into a hopper and is carried forward by a woven belt of corrosion-resistant wire. A paddle wheel forces wash water in a pulsating motion up and down through the belt, gently agitating the fruit. The latter is turned over constantly, thus providing thorough cleaning. In a machine having a capacity of 125 bushels of strawberries per hour, the belt width is 20 inches, and the machine length approximately 13 feet. This provides sufficient space to allow the fruit to drain before being discharged.

Vegetable Washing. For cleaning such commodities as peas, beans, and whole kernel corn, three distinct washing functions are built into one machine known as the Scott Washer (see Fig. 16.9).



Courtesy Scott Viner Co.

FIG. 16.9. Scott Washer.

One portion of the machine consists of a long, two-section ripple-equipped flume for the removal of heavy impurities. When whole kernel corn is being treated, these ripples are replaced with silking combs.

A second part of the unit is a large flotation skimmer for the removal of light floating materials. Elimination of mechanical skimmers avoids crushing or other damage to delicate foods.

The third section is a large separating and washing cylinder screen for removal of water, hulk, skins, and splits. This screen is interchangeable, thus accommodating a variety of products.

A final clean water spray completes the washing cycle. The Scott Washer is economical to operate since no make-up water is required. The final fresh water spray is sufficient to recondition the main water supply. The overflow from the skimmer, plus the water taken out through the split remover screen, returns to the fine mesh revolving screen clinder located over the supply tank. This fine mesh screen removes the solids and passes the water into the tank. A traveling spray of fresh water plays on the outside of the screen to keep it clean.

AERATING (ASPIRATING)

Cleaning by air blast may be accomplished when the foreign material to be removed is substantially lighter in specific gravity than the product to be cleaned. The air cleaning of peas is a typical case in point. Much of the trash brought in with the peas from the vines, such as leaves and hulls, can be blown out with a blast fan. The effectiveness of the air blast is often increased by simultaneously vibrating and screening the product to be cleaned. Fanning mills are extensively used in the cleaning of grains.

Various cleaners have been designed which utilize air currents to separate light from heavy particles. Combination cleaners, performing several functions, are used in the milling industry. A coarse screen eliminates contaminants with a diameter larger than the cereal grain being cleaned. A fine screen removes sand and small seeds. Finally, by the suction of a fan, light impurities, such as chaff, hulls, dust, and light grains are eliminated, the heavier portion being deposited in a settling chamber, the ligher portion in a dust collector.

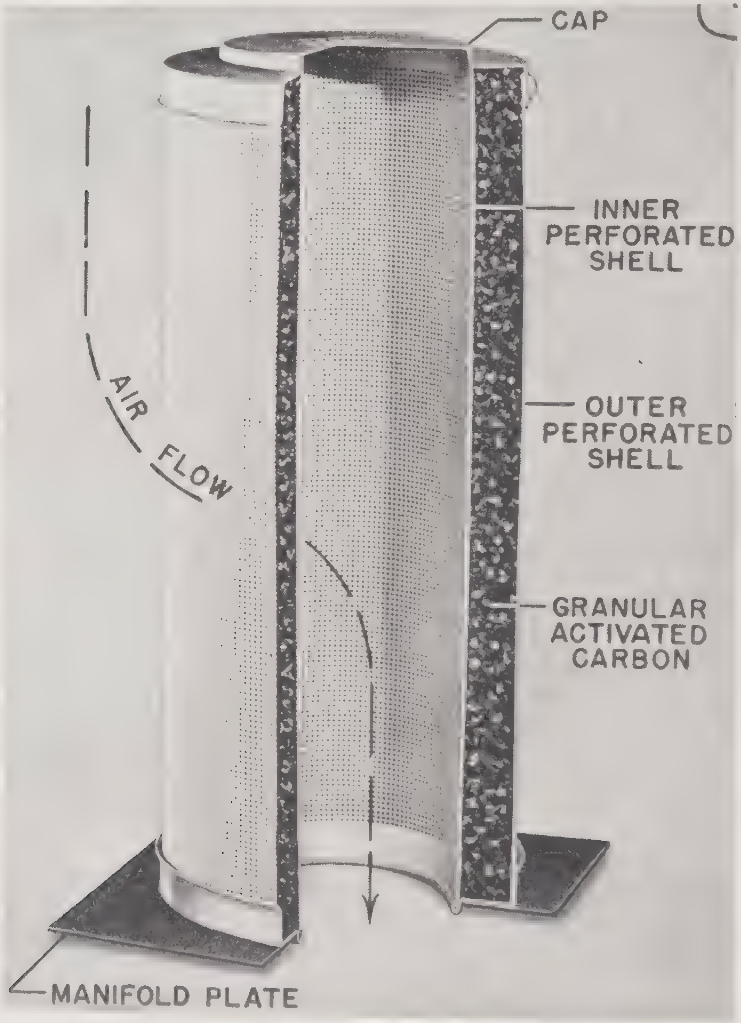
It was previously mentioned that air cleaning appears to be replacing the rinsing of new glass or single-trip containers. The introduction of a high-velocity stream of air into any container, either of glass, metal, or other rigid construction, will normally remove any dust, carton lint, glass or metal chips, and other loose foreign material that may have entered the container between the time of its manufacture and its appearance in the packaging line. Obviously, this method of cleaning containers is limited to those which do not require sanitizing or a sterile condition at the point of filling.

There is another type of air cleaning in which the product being cleaned is subjected to high velocities, the resistance of the surrounding atmosphere providing the aerating effect. Such cleaning is called "scouring" when applied to wheat. Many special machines have been developed for removing the various types of contaminants in wheat. The preliminary cleaning involves the use of sieves, air blasts, and disc separators. This is followed by dry scouring. In the scourer, the wheat is forced against a perforated iron casing by beaters fixed to a rapidly revolving drum. This severe treatment removes foreign material lodged in the creases of the kernels as well as the brush hairs. Many American mills are equipped with wheat washers in which the wheat is scrubbed under a flowing stream of water. The washed wheat is passed through a "whizzer" (centrifuge) which removes the bulk of the free water (see Fig. 5.3, Volume I).

Still another form of aerating cleaning operation involves the cleaning of fruits and vegetables by the use of a dual purpose unit known as a washer elevator. It consists of a pump which elevates and conveys the product to any specified place. The unique cleaning action is accomplished through the use of water and air, the latter being incorporated under pressure (aerating the water) to produce suds by the mixing action alone and without the use of any detergents. Whole, sound stock is not injured as the product is carried in a cushioning bath of turbulent water which removes dirt and other foreign material.

Purification of Air

In some food industries in critical processing operations, purification of the atmosphere itself is desired. Air contamination of food products sometimes has to be avoided not only with respect to possible microbiological contaminations such as bacteria, yeasts, and molds but also with respect to tainting odors which might be introduced in aerating operations unless the air itself is first purified.

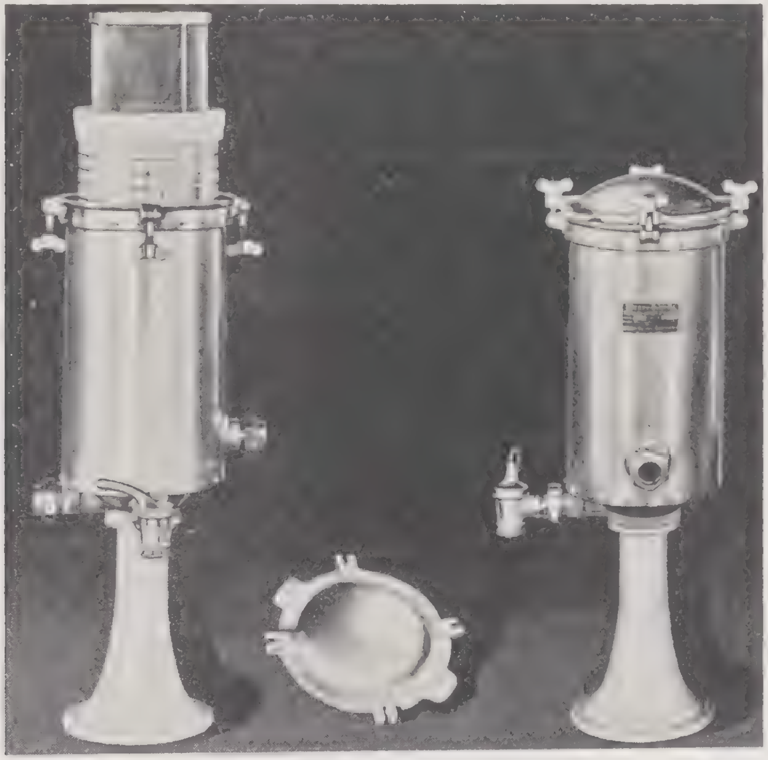


Courtesy "Food Processing"

Fig. 16.10. Cut-away view of an air purification canister showing the uniformly thick bed of activated carbon which absorbs gases and vapors.

Sterilization of air by bactericidal ultraviolet radiation (2,537 Ångstrom units wavelength) appears to have been successfully applied in some applications, although the evidence is not generally acceptable. The cleaning and conditioning of air by drawing the outside atmospheric air through a bank of mechanical filters and water washers, and in some instances through electronic units ("Precipitron") have been reportedly effective. Many air-cleaning methods are evaluated on the basis of weight tests whereby artificial dust removal can be expressed on an efficiency removal basis. However, weight tests are probably not as dependable in measuring effectiveness of air cleaning as sediment tests. This has been demonstrated in measuring the effectiveness of electronic air cleaners. Comparable evaluations of most mechanical filters by visual sediment tests (known as blackness tests) have been found to be but 10 to 20 per cent efficient, whereas on a weight-test basis their efficiencies were much higher.

Spraying hypochlorite mists into air has been found more effective than ultraviolet radiation against infected particles. The practical objections to bactericidal mists are their odor, possible toxicity after long exposures, and corrosive action upon metals and clothing. Commercial air washers and

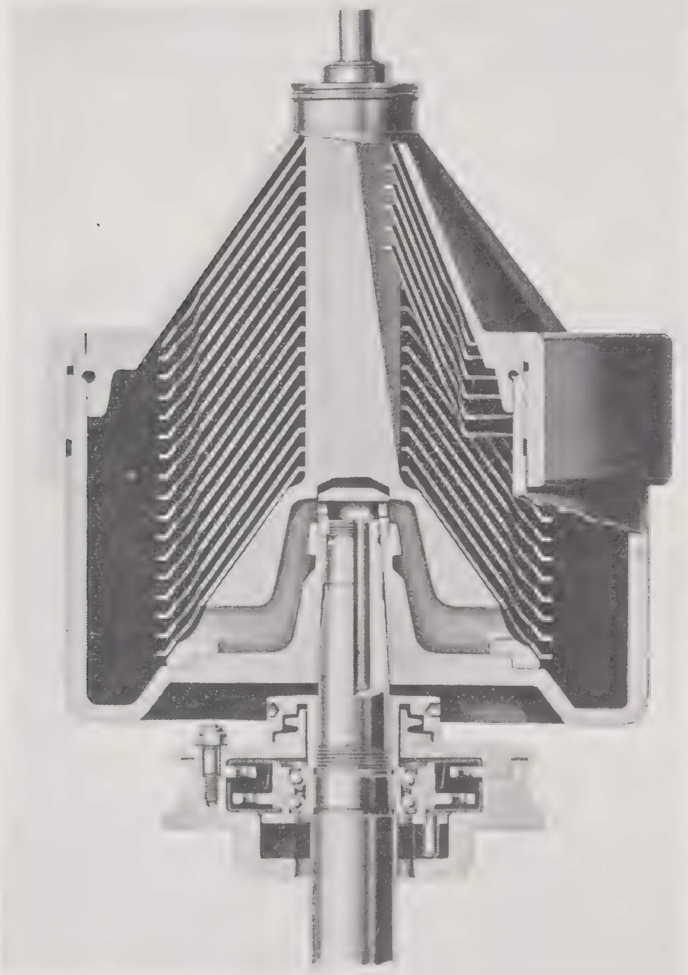


Courtesy Cherry Burrell Corp.

FIG. 16.11. A sanitary pressure milk or cream filter.

filters may remove as much as 80 per cent of dust-borne organisms in the air passing through them. On the other hand, too much ventilation may actually increase pollution of air by stirring up organisms and dust particles from the floor. Much depends, of course, on the design of air-distributing system.

Cloth and paper filters are fairly satisfactory in removing pollens and dust whereas particles less than 10 microns in size are more efficiently removed by electrostatic precipitators (precipitrons). In dust purification systems, the use of activated carbon cannisters have proven effective in removing gases and vapors by the process of adsorption which is useful where odor taints must be guarded against (see Fig. 16.10).



Courtesy DeLaval Separator Co.

FIG. 16.12. Cut away diagram of disc bowl used in clarifying milk. Note relatively wide spacing between outer peripheries of discs and inner side of bowl wall to permit accumulation of sediment. Also note that inlet holes at 180° in each disc are close to outer peripheries of each disc.

FILTERING (CLARIFYING)

In the dairy industry, the terms clarifying and filtering refer to the operation of removing dirt and visible foreign particles from milk. Under the usual conditions of obtaining milk from the cow, dirt and other foreign material are introduced. To remove this contamination, the dairyman strains the milk through cotton pads into the shipping can and the operator at the receiving station may strain the milk again. While these preliminary operations are helpful, they are not sufficient. Before pasteurizing, therefore, the milk is filtered or clarified.

Milk may be filtered cold or hot, and there are proponents of both methods. Since heat decreases the viscosity of the milk, thereby increasing the ease with which it will pass through the small pores of the filter, it is usually put through a tubular heater at 90 to 95°F.

The important features of the milk filters currently being used are.

(1) A filter cloth or pad designed to hold the smallest particle visible to the eye.
(2) A frame to hold the edge of the cloth or pad.
(3) A wire screen or perforated metal sheet to support the cloth or pad.
(4) A chamber divided into two portions, the front being the inlet for the milk and the rear for the filtered milk, the filtering medium being the central partition.
(5) Means of so distributing the milk so that its turbulence does not injure the filtering medium.
(6) A design that permits the filter cloths or pads to be removed conveniently and renders the interior accessible for thorough cleaning.

Milk filter cloths are customarily canton or outing flannel. The straining pads are alternate layers of carded cotton.

The milk filter (see Fig. 16.11) is operated by pumping the milk through the closed system under pressure, using a sanitary pump. Filter cloths must be changed every hour or two, depending upon the degree of contamination, the temperature of the milk, and the amount of detritus from the udder of the cow. To avoid loss of time when a filter must be cleaned, especially where continuous operation or large volumes of milk are handled, two filters should be available. The filter cloth or pad must never be used a second time.

The mechanical clarification of milk is accomplished by means of centrifugal force. The bowl of a milk clarifier is constructed similarly to that of a conventional cream separator except that (1) the discs are shorter to provide greater sediment-holding space, and (2) there is but one outlet from the bowl. Milk is delivered into the bowl at a point near the outer edge of the disc and travels inward and upward through the discs (see Fig. 16.12). Any solid material present is thrown outward into the sediment space. There is no separation of milkfat from the milk. Accumulated sediment is removed from the bowl at appropriate intervals, depending, of course, upon the size of the clarifier and the relative amount of sediment in the milk. The operating period, therefore, may vary from 30 minutes on a small machine with relatively "dirty" milk to as long as 8 to 10 hours on a large machine if, in the latter case, the milk itself is relatively free of sediment.

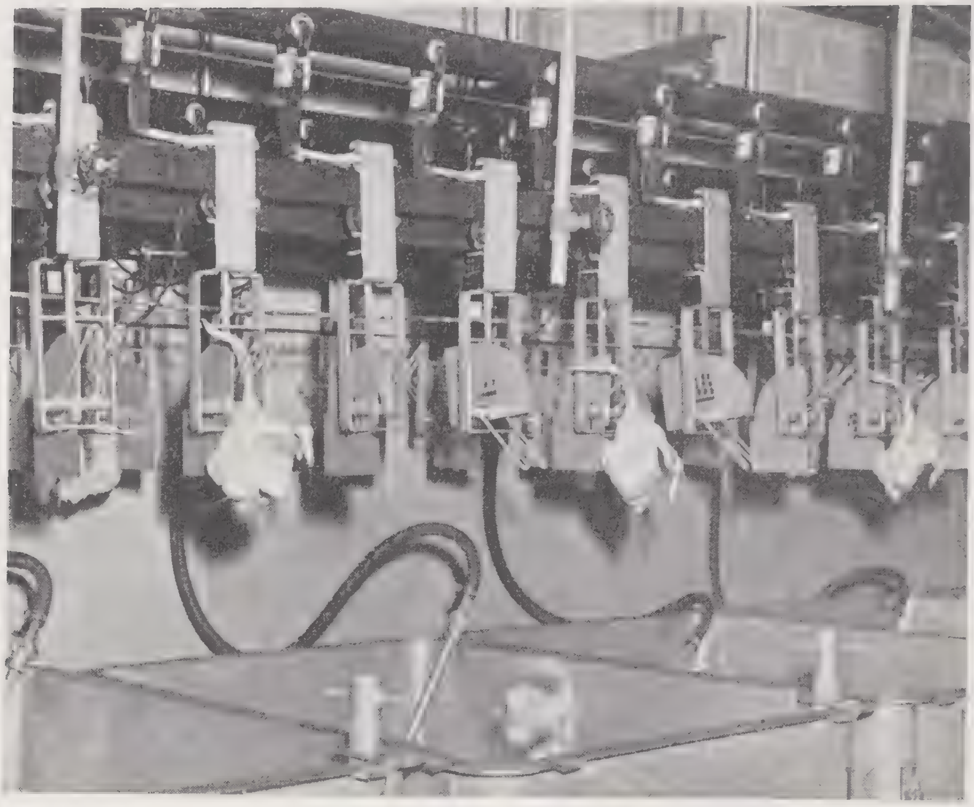
17. Separating (continued)

Separating, considered as a unit operation, is involved in many phases of the production, preparation, processing, and distribution of foods. Actually, it is not possible to have any definite lines of demarcation between one unit operation and another, for in the preparation of foods for their subsequent processing, we continue to be concerned with sorting as well as peeling and trimming, etc. Such operations further enable us to reject underdeveloped, damaged, or overripe products that the original grading during the assembly of raw materials does not always provide. While the commercial advantages of the preliminary grading practices are too obvious to be debated, it might be noted at this point that during the preparation of raw food materials for their subsequent processing, and packaging, their separating continues systematically and progressively a common practice in most food industries. It is generally conceded that the quality of any final product depends largely upon the effectiveness of the grading and its subsequent separating operations and where they can be repeatedly and continuously applied in conjunction with other incidental unit operations, the quality control will be that much more adequate and effective.

SORTING

Sorting involves inspection, followed by separation according to variety, size, color, degree of ripeness, maturity, defects, etc. and actually is a separating operation supplementary to grading (see Fig. 17.1). Sorting is a form of separation of food materials and food products at any stage of processing, whereas grading occurs only during the assembly and receipt of raw food materials for the purpose of establishing their commercial value. Overripe fruit products, for example, are rejected because they will disintegrate when cooked, thereby spoiling the appearance, and perhaps the grade, of the finished product with economic penalties in many instances. On the other hand, underripe products will not only lack flavor but may also contribute undesirable characteristics such as astringency, sourness, bitterness, off color, and unappealing or even objectionable odor.

Effective sorting requires good light, proper atmospheric conditions, comfortable chairs of proper heights with back supports, and reasonable



Courtesy USDA-PMA

FIG. 17.1. An automatic poultry-sizing machine capable of sorting dressed poultry varying as little as one ounce in weight. The dressed poultry are placed on the hangers of the endless belt to be dropped into the appropriate tubs.

rest periods. In other words, since sorting is inspection work, it is necessary to avoid fatigue of the inspectors which means attention to details of bodily and mental comfort. Well modulated musical programs played at proper intervals will reduce monotony as well as tend to minimize talking among inspectors which can become distracting if not properly controlled.

It is good practice to establish the necessary light intensities for various tasks with the aid of a light meter, much as heating an office is controlled by a thermometer. Sorting and grading will sometimes require as much as 100 foot-candles, whereas 20 foot-candles may be enough for receiving and storing operations. However, merely providing the proper intensity of light is not sufficient, inasmuch as the absence of glare, proper light distribution and diffusion, and color quality are equally important. Adequate ventilation is also important and it has been observed that the mean effective temperature for comfort in summer is approximately 70°F and in winter about 65°F, with air movement at the rate of about 20 feet per minute.

Sorting is generally best done by women inspectors. Ease of inspection will facilitate its proper performance. Long tables with conveyor belts on each side to carry the products and a center conveyor belt operating in the opposite direction for rejects make for effective and sorting inspection provided both belts are within easy reach of the inspectors. Instructions as to what to accept and what to reject must be clear and concise. After all, sorting is an important unit operation with decisive influence upon profit and loss. Rigid inspection makes for high costs whereas reasonable tolerance will generally prove both effective and economical.

DRAINING

The soiled water resulting from the washing of a raw food is usually separated by draining while in the washing equipment. Separate revolving reels or basket centrifuges are available, however, when a more thorough draining is necessary following grading, washing, or blanching. Draining is also important in removing wash water from food containers, overflow from filling operations, and any spillage which might occur.

Cans to receive syrup additions are first washed and rinsed. In draining the cans, one design of drainer causes them to pass around a turret rotating in a vertical plane whereas in an improved model, the turret rotates in a horizontal plane, the cans being tipped to a 120° angle before being returned to a vertical position for passing into the syruper.

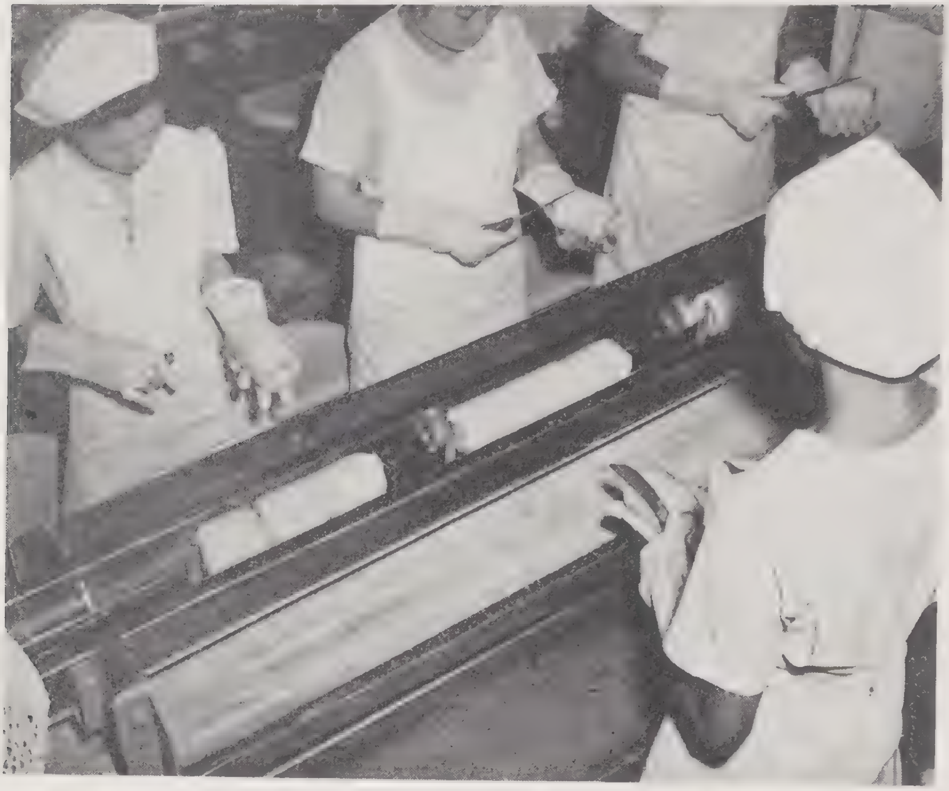
Draining is also an important operation in dispatching and dressing animal products as will be discussed later in this chapter.

TRIMMING

Trimming may be the removal of undesirable portions of raw foods as a result of the sorting operation mentioned above. If so, the same type of equipment may be employed, the workers using sharp knives to cut off or cut out the unwanted portions (see Fig. 17.2).

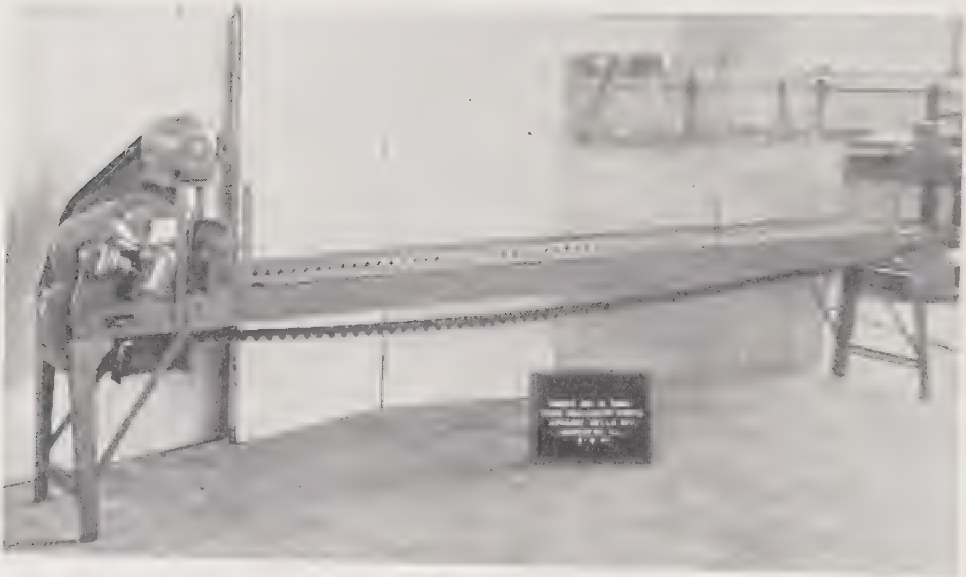
Foods, like all other agricultural products as they come from the field, are not uniform. The food manufacturer must look simultaneously in two directions, keeping one eye on legal and ethical requirements, the other on expense items which contribute to higher costs. Obviously, trimming of the type under consideration must be done intelligently.

In canning corn on the cob, it is important to have all ears the same length. A trimming machine consists of a pair of spaced rotary cutting discs and a pocketed endless conveyor (see Fig. 17.3). Ears are placed manually in the pockets with one end bearing against a stationary guide bar. The conveyor carries the ears between the cutting discs which are spaced apart to the desired trimmed length. A short endless flat belt operating between the cutters bears against the ears to hold them firmly in the pocket. Length



Courtesy Libby, McNeill & Libby

Fig. 17.2. Trimming shelled and cored pineapples.



Courtesy Food Machinery & Chemical Corp.

Fig. 17.3. Corn trimmer.

of cut can be adjusted from 4 to 5½ inches to suit can lengths. The standard trimmer is 15 feet long, thus permitting five operators on each side of the conveyor. Two hundred ears per minute is good output.

Carrots can be trimmed by a machine that utilizes two separate cleated canvas belts which carry the carrots through the machine crosswise. As the carrots approach the first set of cutting knives, the belts gradually tilt to allow the product to slide to the outside edge of the machine for the trimming cut. As they approach the second set of knives, the carrots slide toward the inside of the machine. Thus both ends of the product are trimmed, the amount of the trimming cut being adjustable. For carrots from 1 to 1½ inches in diameter, the capacity of the machine is about 5 tons per hour.

PEELING

The removal of the outer layer of a fruit or vegetable is variously referred to as peeling, paring, and skinning. The distinction is difficult to find. By common usage, apples are "pared" and sweet potatoes are "skinned".

Hand Peeling

The removal of the outer skin of fruits and vegetables by hand as been been abandoned as rapidly as equipment and other techniques made it possible. Hand peeling is slow, costly, and wasteful of the product even though knives with adjustable guides regulate the depth of peel.

Uses of Heat in Peeling

When tomatoes are immersed in boiling water for 30 to 60 seconds and then sprayed or immersed in cold water, the skins loosen, making them easily removable by hand. Passage of the tomatoes through a steam chest, followed by cold water, is extensively used for the same purpose.

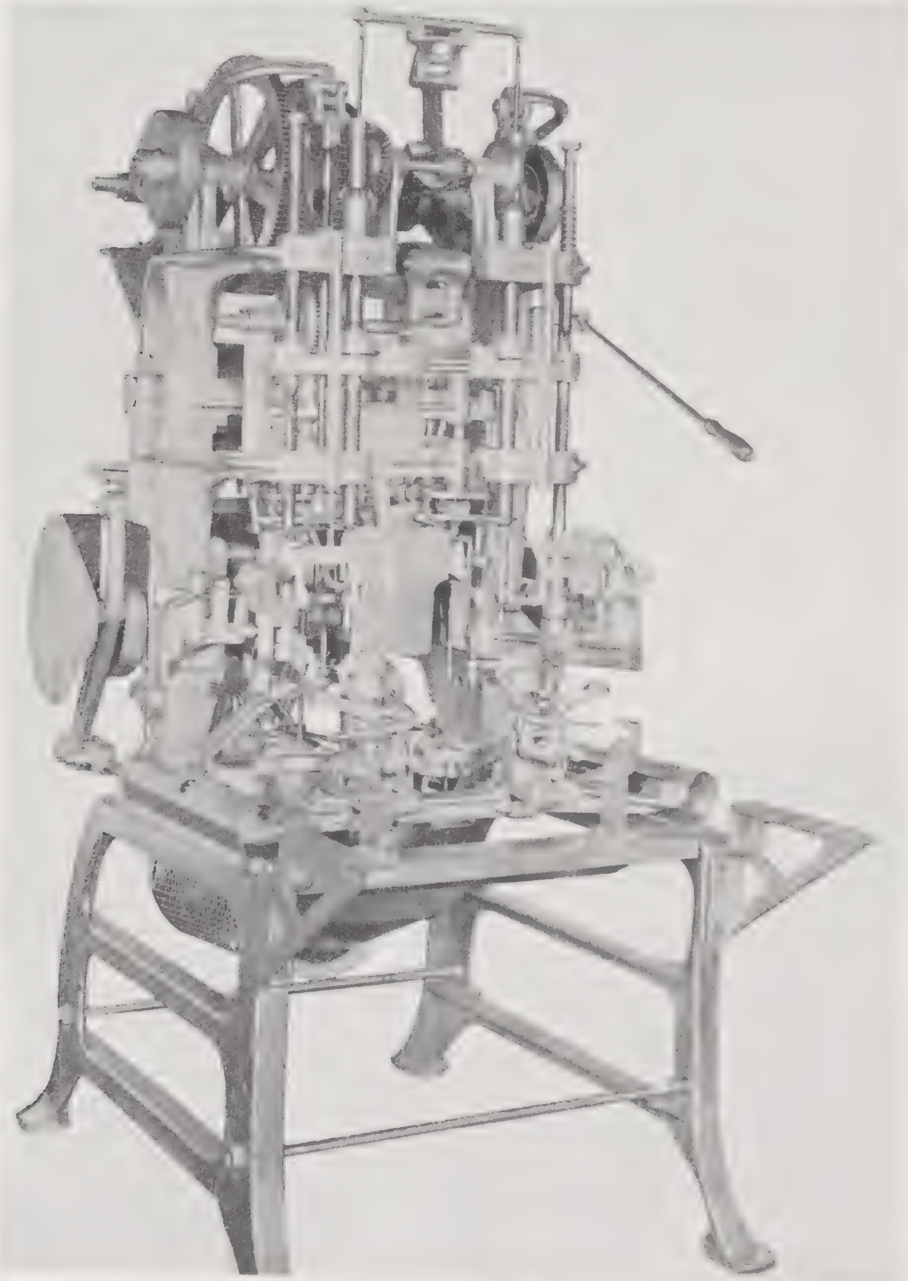
Certain varieties of peaches and beets may have their skins loosened by passing the product through a steam box for two or three minutes, or by submerging in boiling water for a short time.

Several methods are used for the peeling of pimentos for canning. The process of subjecting pimentos to a dilute boiling lye solution to facilitate peeling has been abandoned. A roasting process in which the pimentos are passed through direct gas fired revolving steel cylinders is satisfactory. Another usual method is to subject the pimentos to a bath of cottonseed oil heated to about 400°F.

The skinning of sweet potatoes may be accomplished by steaming. The potatoes are placed in crates and held in retorts at 240°F for about 10 minutes, after which time the skins will be softened and loosened. The steamed potatoes are removed at once to the peeling tables where workers slip off the skins or jackets, the hands being protected with heavy gloves.

Peeling by Mechanical Means

One machine designed for apple peeling will also remove and core and seed cells (see Fig. 17.4). While the machine runs continuously, the operator



Courtesy Food Machinery & Chemical Corp.

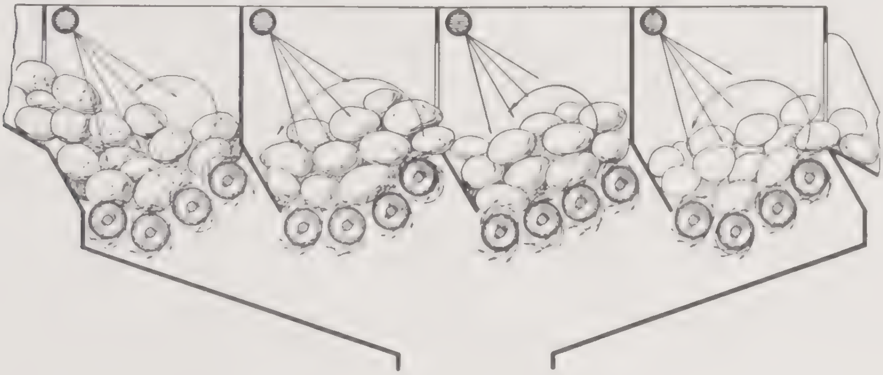
FIG. 17.4. Front and side view of apple parer with inside slicer and seedcell scoops.

manually places two apples simultaneously on feed cone cups where they are held by centering jaws while being transferred to paring and coring spindles. The position of the apples may be adjusted to permit uniform peeling—an essential feature in handling different sizes. Knives remove the skins from the entire surface of the apple in a thin uniform layer, the thickness being a matter of adjustment.

Capacity of such a machine is about 135 bushels per day. Following removal of the core and seed cells, the apples may be sliced automatically and placed in dilute brine to prevent browning. Under the best conditions, peeling and coring losses run as high as 35 per cent. This trim material may be sent to a vinegar factory, or used for jelly and pectin.

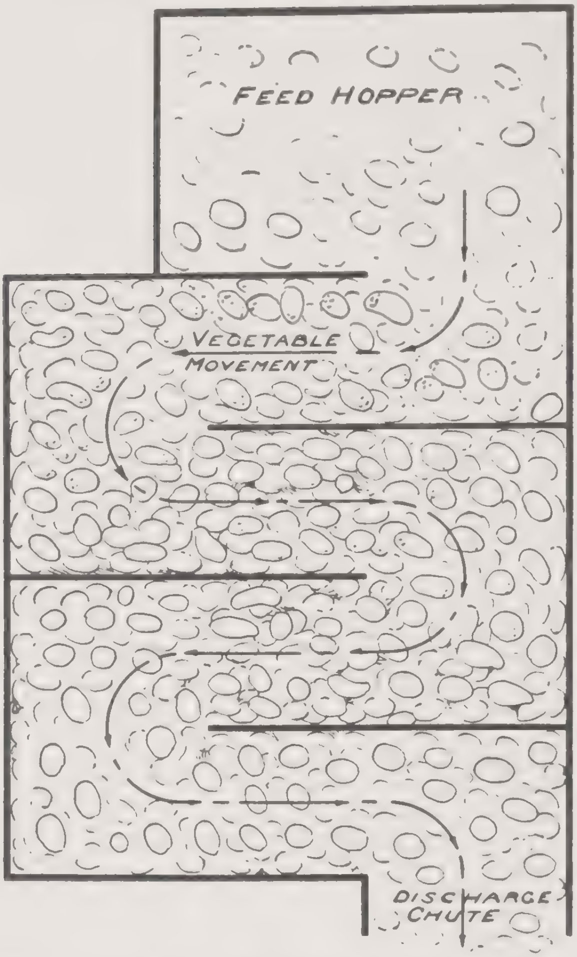
Root vegetables, such as potatoes, beets, carrots, turnips, parsnips, and onions, may be peeled mechanically in an upright cylinder, in the bottom of which is a rotating disc. The upper surface of the disc and side walls of the cylinder are coated with an abrasive. The centrifugal force of the disc throws the vegetables against the abrasive, thereby removing the skin. A water spray flushes the skins from the vegetable. To obtain good results with minimum losses, the operator must be conscious of the important variables, i.e., coarseness of abrasive, size of load, length of operation, and toughness and thickness of skin to be removed.

Urschel has developed a continuous vegetable peeler that has an output of about two tons of medium size root vegetables per hour (see Fig. 17.5 A & B). The unit consists of four bins. In the bottom of each bin are four



Courtesy Food Machinery & Chemical Corp.

FIG. 17.5A. Diagrammatic sketch of continuous vegetable peeler illustrating peeling principle. Each of the four bins has four carborundum coated rolls all turning in one direction at high speed. These rolls remove almost instantly the peeling of the vegetables being peeled. The four rolls in each bin are divided into pairs and the rolls in each pair fastened together. Each connected set of rolls has a separate rocking motion which turns the vegetables over and over. Thus, the vegetables are peeled completely as they move from the feed hopper on through to the discharge spout of the peeler.



Courtesy Food Machinery & Chemical Corp.

FIG. 17.5B. Diagrammatic sketch of continuous vegetable peeler illustrating vegetable movement. The drawing shows the course followed by vegetables as they "flow" through the Continuous Peeler. The first, second and third bins contain coarse, rapid peeling carborundum-coated rollers. The rollers of the fourth bin, coated with fine carborundum, do the "finishing". Thus, without the necessity of employing a "finishing machine" as required by other types of peelers a highly and economically finished product is obtained.

carborundum-coated rolls divided into pairs. Each connected set of rolls has a separate rocking motion for turning the vegetable over. By varying the degree of coarseness of carborundum from coarse to fine, the vegetables are thoroughly cleaned as they pass over the high-speed rolls on the way through the machine.

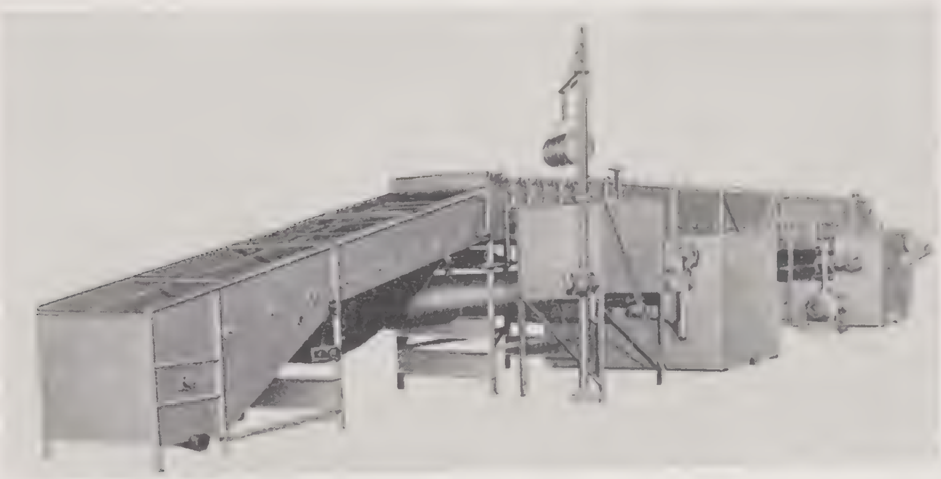
The (peeling) skinning of potatoes, carrots, turnips, and beets may be accomplished mechanically following a pressure steaming operation. The machine is a rotary rod type. The rods are half oval and spaced $\frac{5}{8}$ inch apart, running longitudinally with the cylinder and around its entire periphery. Six longitudinal equally spaced pick-up flights are provided for maximum tumbling effect. The cylinder is tilted slightly toward the discharge end so that a continuous flow of skinned product falls over the top of the discharge baffle as the cylinder rotates. Water is applied continuously at 50 to 60 psi through a spray header running through the center of the cylinder. A 10 to 12 foot long machine has a capacity of 5 to 8 tons per hour.

Peeling by Chemical Means

The first use of a dilute boiling solution of lye to soften the skin of a food was in the preparation of hominy. Corn is boiled in a dilute solution of sodium hydroxide and the loosened skins removed in revolving cylinders while washing with water.

In 1902 patents were granted for the lye peeling of fruits. The small amount of residual lye remaining on the peeled fruit is neutralized by the acidity of the fruit. Lye peeling causes less loss of fruit, permits more rapid handling, and is lower in cost than other methods of peeling.

Of the various machines used, the Dunkley Lye Peeler is typical (see Fig. 17.6). It consists of a long sheet metal box through which an endless woven-wire belt carries the product to be peeled. At the entrance the product is sprayed with hot water. The fruit is then subjected to sprays of $1\frac{1}{2}$ to 3 per cent lye solution at 208 to 212°F applied from above and below. The hot water and lye solution drain into reservoirs below the peeling compartment and are recirculated by pumps. After passing the lye sprays, the fruit is sprayed with fresh cold water to remove the skins and rinse the



Courtesy Food Machinery & Chemical Corp.

FIG. 17.6. Dunkley peach peeler and washer.

lye from the fruit. When the unit is intended to handle peaches, a steam blanch immediately follows the cold water wash, thus preserving the color.

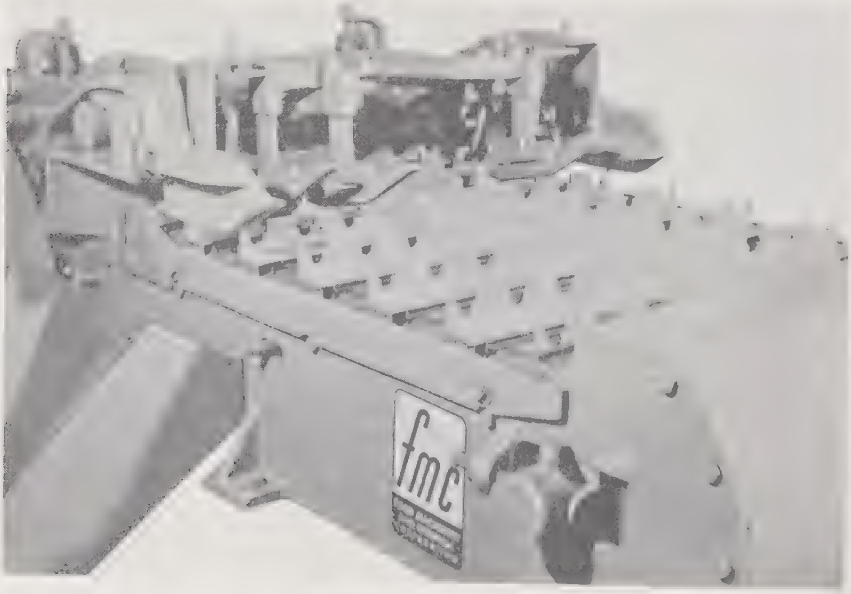
Husking

This is a specialized type of peeling, the term being applied to the removal of the outer covering of an ear of maize, or Indian corn.

The basic design for a corn husker consists of a pair of rapidly revolving rubber or milled steel rolls against which the ear is held. The rolls are spirally grooved and catch the husks and remove them in a manner somewhat similar to the way clothes are carried through a wringer. Water plays on the rolls to prevent injury to the corn in some machines. A favorite model, known as the Double Husker, is equipped with two pairs of husking rolls and will handle ears as fast as two speedy operators can feed them, i.e., 2 tons per hour (see Fig. 17.7).

Shelling

Another specialized type of peeling is shelling. Shelling is the operation of removing peas from their pods after picking from the vines. Machines are available with various capacities, although all of them are similar in their design principles. An outer hexagonal perforated drum, provided with inside projections and an internal shaft upon which beaters are attached, revolves, carrying the pods to a critical height so that when they fall, they are struck by beaters revolving rapidly in the opposite direction to that of the drum itself.



Courtesy Food Machinery & Chemical Corp.

FIG. 17.7. Double Husker.

Shelling differs from vining in that the latter is the operation of removing pods from the vines, and at the same time shelling the peas or lima beans. To avoid long haulage of bulky materials, vining is usually done in the field.

The vining machine is a perforated metal drum, inside of which are beaters rotating rapidly on a central shaft in a direction opposite to the movement of the drum. The pods are torn from the vines and the product shelled by impact with the beaters. Openings in the drum permit the peas or beans to fall through while the vines are carried through the cylinder to a conveyor. The forwarding action of the beaters is accomplished by pitching the latter at an angle. The length of time the vines remain in the viner depends upon the pitch and speed of the beaters. This threshing action must be accomplished with a minimum of injury to tender peas and lima beans. Vining is discussed in more detail in Chapter 14 under the heading of Harvesting.

PITTING

The removal of pits from fresh apricots, cherries, prunes, and similar products may be done by machine. The operation is simple, effective, and economical. When dried prunes are to be pitted, they must first be thoroughly steamed or softened. For any large-scale manufacturer of fruit juices, jams, bakery and quick freeze fruit products, such equipment is indispensable.

The machine consists of two revolving rolls, one of soft rubber, the other of a series of steel saws spaced approximately $\frac{1}{8}$ inch apart. The whole fruit is fed directly to these rolls by a feed shaker on the machine. Extractors set between the saws on the front side of the roll strip out the pitted fruit onto the discharge chute. A knife on the under side scrapes off the pits adhering to the teeth of the saws to a discharge shaker. This shaker is equipped with a special screen and discharge pan so that any juices carried over with the pits can be drained off. Fruit is fed between pitting rolls by means of an automatic plunger driven directly from the machine. The fresh fruit pitter under discussion is 44 inches wide and 5 feet long, and will handle 1 to 2 tons per hour.

Sweet cherries are usually canned with pits intact. This adds to the appearance as a dessert fruit and contributes to the flavor, the pit containing benzaldehyde.

Sour cherries are used for baking and are almost invariably pitted. An early machine consisted of a cylinder with a row of cups upon its inside circumference. The cherry rolled into a cup, was centered by a cup-like device, and the pit forced out by a quick acting plunger. The pit passed to the center of the cylinder and was carried off, while the fleshy portion was dropped out of the cup as the cylinder revolved. Capacity was about 1200 pounds per hour. It was not suitable for fancy quality since two holes were made in the cherry, one where the plunger entered, the other where the pit was forced out. The bulk of such a pack is in No. 10 cans for hotel, restaurant, and commissary supplies.

CORING

Fruits with small seed cells located centrally, such as apples, are cored by hand or machine. When done mechanically, a cylindrical core about 1/4 to 5/16 inch in diameter is removed, usually as part of the peeling and trimming operation (see Fig. 17.4). In addition to eliminating this undesirable portion of the fruit, the worm and mold content is lowered, since this type of infestation is frequently high near the core.

The principle of the turbine has been applied to the hydraulic coring and trimming of fruits. The coring knife rotates in the center of the turbine. A rubber diaphragm with a hole in the center, and soft enough to yield to the pressure of the fruit, permits the knife to protrude, yet protects the operator.

Pineapple is peeled and cored automatically by feeding the fruit to a Ginaca machine by means of an endless conveyor. Both ends are trimmed off, the fruit sized and cored, and the skin removed (see Fig. 17.8).

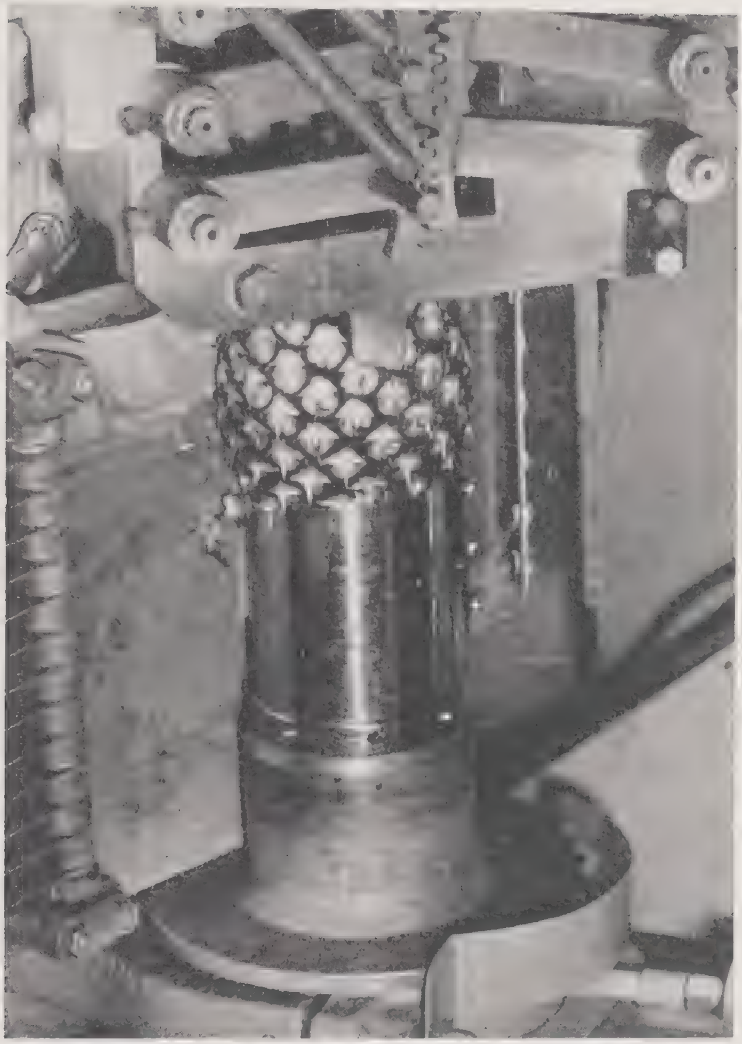
STEMMING

Certain fruits must be picked with the stems attached, such as cherries and grapes. These are removed later by machine.

The cherry must be tree-ripened before picking, proper flavor not developing until ripe, and ripeness not developing off the tree. To prevent rupturing of the flesh, loss of juice, and contamination, the stems must be attached when picked. Cherries should be handled in shallow boxes or trays to avoid bruising.

In many plants stemming is still done by hand, but equipment is available for this operation. The machine consists of a slightly inclosed cylinder 2 feet in diameter and 4 feet long, rotating at 20 to 30 rpm. The cylinder consists of a series of short rubber rolls about 3 feet long and one inch in diameter. As the cylinder rotates, the rubbers are engaged at one end by a cogwheel when the rollers are at the lower position during rotation. As the rollers turn, they catch and pull through stems and leaves, leaving the cherries uninjured on the inside of the cylinder. Feeding occurs at the upper end, and the cherries emerge at the lower end, with 95 per cent of stems removed. The balance is done by hand, following which all cherries are washed and graded for size.

The Thompson seedless grape may be stemmed by machine although the Concord grape cannot be successfully stemmed mechanically.

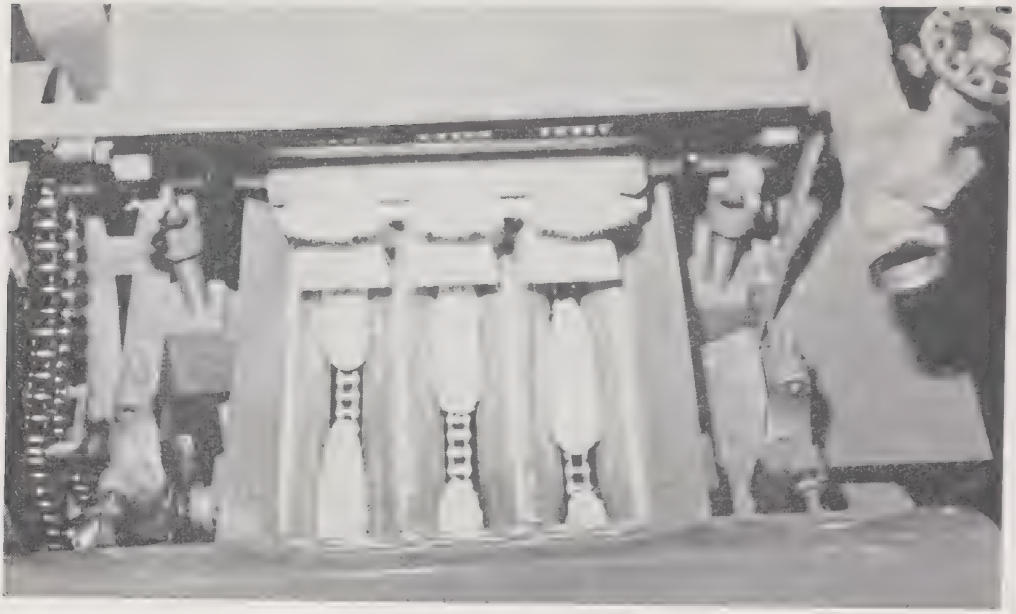


Courtesy Libby, McNeill & Libby

FIG. 17.8. Ginaca machine removing shell and core of pineapple following its careful sorting and thorough washing.

SILKING

Silking is an operation applied exclusively to corn. It can be performed continuously. In such case, husked corn is spouted to hoppers feeding rotating flat-sided reels. Cob particles, silk, and foreign matter are removed and discharged fom the reels into a waste collecting pan. The corn then drops through the wire mesh into contact with traveling wires. Remaining silk clings to the wires and is discharged into waste collecting pans by action of a rotary brush. From the traveling wires the corn drops onto shaker screens which sift out any remaining foreign material, leaving the clean corn to pass through into the product collecting pans.



Courtesy Food Machinery Corp.

FIG. 17.9. Corn silk brusher in which ears revolve on rotating rollers while being moved forward by lugs on the chain. Water sprays and rotating brushes wash and silk the ears as they are carried forward.

A more elaborate machine has been developed for automatically scrubbing and washing husked ears of corn (see Fig. 17.9). Revolving brushes remove milk, dirt, and ear worms by wiping against its kernels in a forward direction as the ears are carried through the machine lengthwise. The bristles reach down into the rows of kernels dislodging unwanted material, while the ears rotate constantly. Overhead distributors play water sprays on the ears and brushes, thus washing the ears, flushing away the debris, and keeping the brushes clean. This machine was designed to clean ear corn prior to cutting from the cob.

FLOTATION

An example of separation by flotation was given under the discussion of pea grading for quality.

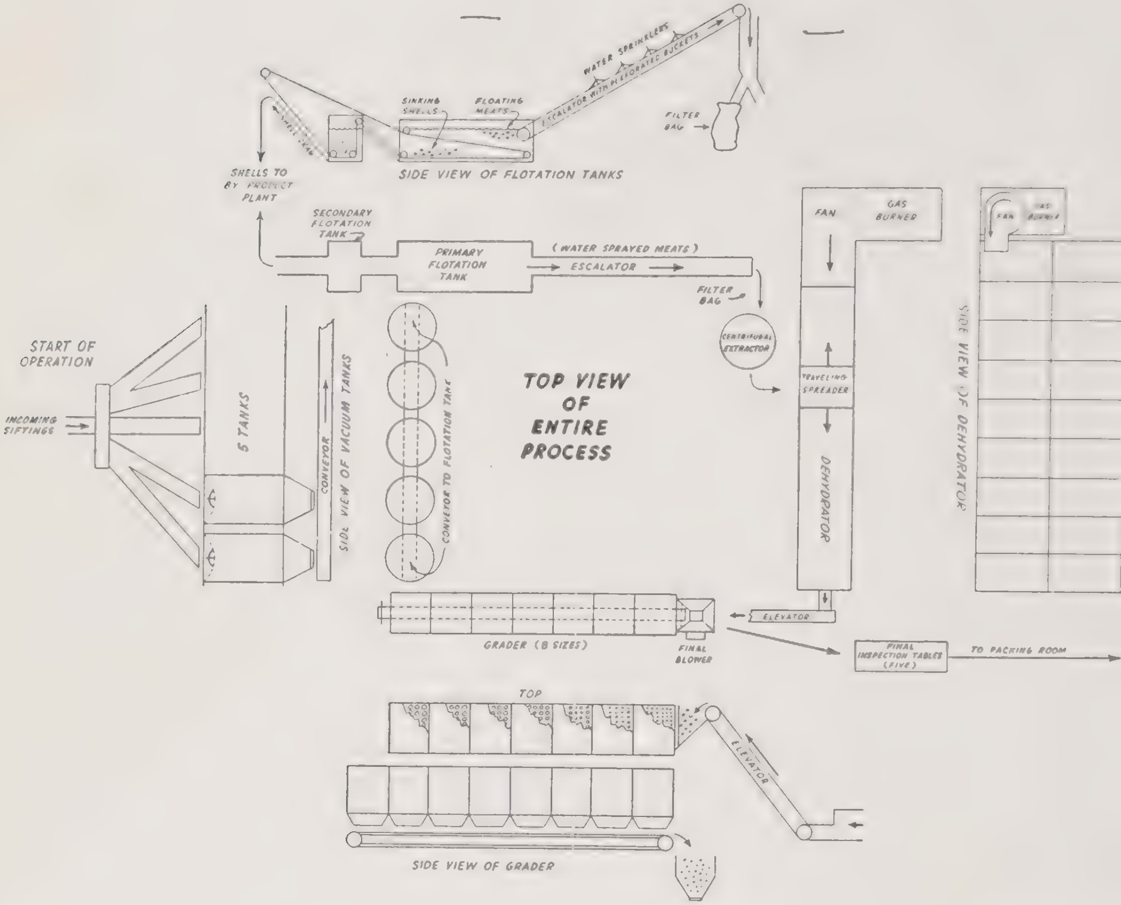
Another interesting application of this principle involving the separation of bran from wheat is practiced in the Earle process. While not now in commercial use, test runs were made by passing cleaned wheat through a series of rubber-lined cells during which it was violently agitated under water by rubber-covered impellers. This removed the bran. The last cells in the series serve as flotation units. By adding a flotation agent and aerating the water, the bran came to the surface and was floated off. The wheat was then recovered by screening and centrifuging.

The flotation principle has also been applied to the recovery of walnut meats from intermingled shells. The apparent specific gravity of walnut meats and shell fragments is essentially the same. However, when the air removed from the cellular and interfragmental spaces is displaced with water, the shells assumed a specific gravity of approximately 1.25, the good meats about 1.00 and the off-grade meats somewhere between these two values. Employing these critical specific gravities by means of selective vacuum, float tank, skimming, dewatering, and dehydrating treatments, it is possible to realize a satisfactory separation of sound walnut meats from the off-grade meats and shells. The schematic layout of the flotation process for the recovery of walnut meats from intermingled shells as developed by the California Walnut Growers' Association is illustrated in Fig. 17.10.

The foregoing outlines of the applications of flotation separations suggest their possible extension to other food operations. A brief discussion of the basic principles involved is now in order. Flotation includes any operation in which one solid is separated from another by floating one of them at or on the surface of a fluid. In modern froth flotation, the solid particles are continuously agitated in water upon which a thick layer of froth is maintained. Because of differences in the surface properties, one solid more readily adsorbs the water phase, becomes surrounded by water, and sinks. The other solid more readily adsorbs air and becomes at least partially surrounded or covered by air. The average or bulk density of the solid and adsorbed air bubbles is less than that of water, and the whole mass of air and solid floats to the surface as a froth which continuously overflows the side of the vessel. Because separation by froth flotation depends upon the surface characteristics of the materials, it is capable of separating materials regardless of their densities.

The equipment and operations for flotation were developed in the metallurgical industries, and over 80 per cent of mineral concentration is accomplished by this method. The operation is being extended into other fields of which the foregoing reference to the separation of the hulls of wheat from the kernels is a example. The grading of peas and the recovery of walnut meats referred to are not examples of froth flotation, however.

Because of the importance of surface conditions and the necessity of the air bubbles supporting the solid in the froth, flotation is performed on finely divided material, usually varying in size from 20 mesh to under 200 mesh. The material, reduced to the proper size and of the desired pulp density by a ball mill or other fine crusher, is fed to a conditioning tank which is essentially a cylindrical vessel equipped with an effective agitator. The purpose of the conditioning tank is to bring about the coating of the solid to be floated with the proper flotation reagent. The flotation reagent is fed continuously to the conditioner, sufficient time being allowed to cause com-



Courtesy California Walnut Growers' Ass

FIG. 17.10. Flotation process for the recovery of walnut meats from intermingled shells.

plete "filming" of the solid by the reagent. Floatation depends upon the relative adsorption or "wetting" of the solid surfaces by the fluid. Frothing agents are required to prevent coalescence of air bubbles when they reach the surface of the water in order to maintain a persistent froth. Accordingly, they must be sparingly soluble in water without appreciable ionization and be adsorbed in the interface between water and air, thus tending to reduce the surface tension of water. Collectors and promotors, on the other hand, are reagents which are adsorbed on the surface of the solid as very thin films and which, because of their properties, increase the interfacial tension.

While the reagents normally used in the separation of minerals would not be adaptable for use in food separation operations, the basic principles might be kept in mind for applications where wide differences in specific gravities do not exist but which might be susceptible to froth flotation separation under proper conditions.

CENTRIFUGING

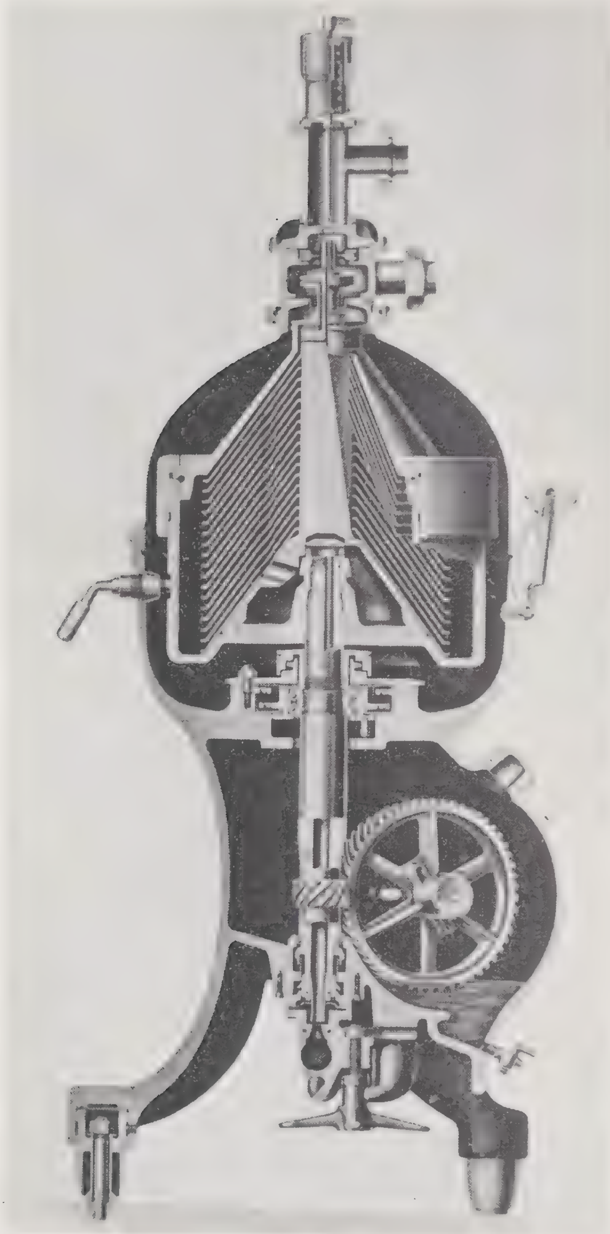
In the preparation of raw food materials in the dairy industry there is frequent and constant resort to centrifugal separators. This machine depends for its action on the principle that centrifugal force greater than that of gravity is often desired for the separation of solids and fluids of different densities.

The high-speed machines used to separate milk into cream (milkfat portion) and skimmilk (serum portion) are generally of two types: the tubular bowl and the disc bowl. The bottle type, a batch machine, is limited to laboratory and analytical separations; a very high-speed batch machine called the ultracentrifuge is used for difficult separations. Disc bowl centrifuges operate at relatively lower speed and have bowsl of larger diameter than the tubular bowl machines. The disc bowl centrifuges are used almost universally in the dairy industry.

In operation, the milk, fed into the rapidly spinning bowl, distributes onto the separating discs in a manner similar to that illustrated in Fig. 17.11. This action imparts a whirling action to the milk, which being subjected thereby to centrifugal force, has a tendency to fly out from the center of the bowl. The heavier of the two portions, namely, the serum or skimmilk, will form a layer on the outer periphery of the whirling mass, while the lighter portion, the milkfat or cream, will collect towards the center of the rotating mass. The incoming unseparated milk forces the separating layers up from the bottom and out at the top of the rotating bowl. Two openings are provided at the top of the bowl for the skimmilk and cream, respectively, to pass out of the bowl. The opening nearest to the center of the bowl will discharge the cream while the other will discharge the skimmilk. Regulating the flow of the cream discharge opening by means of an adjustment screw adjusts the proportion of fat in the cream. If this opening is closed further, it will deflect a larger portion of the flow to the skimmilk outlet and thereby increase the concentration of milkfat in the cream.

The best temperature for separating milk centrifugally is approximately 95°F, although it is sometimes varied between 85 and 100°F. Considerable fat loss will occur if the milk is cold at the time it is separated. Special separators have been developed which will separate milk to form a cream of 82 per cent fat, making so-called plastic cream, which is then cooled on a chilled roller. Normally, cream separators will handle from 2,000 to 11,000 pounds of milk per hour to yield cream testing up to 40 per cent milkfat. It is important to maintain certain limits of operating pressure and capacity if the best results are to be obtained.

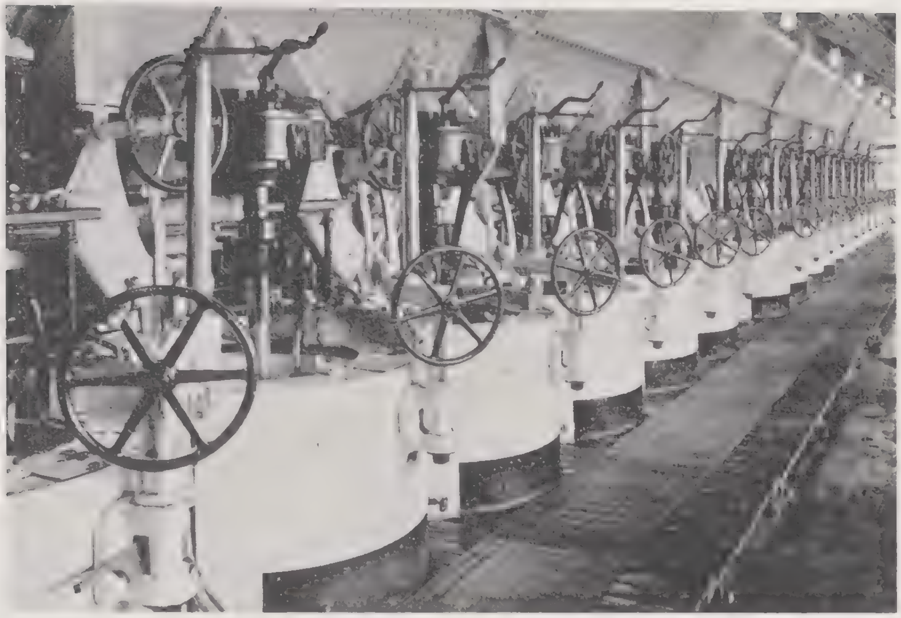
The simplest type of centrifuge is the vertical-shaft perforated-basket centrifugal. The basket diameter is usually 30, 40, or 48 inches in contrast to the 12 to 18 inches diameter of the conventional disc bowl separator. The



Courtesy DeLaval Separator Co.

FIG. 17.11. Cut away diagram of disc separator bowl and driving mechanism such as is used in separating cream and skimmilk.

shaft of the basket centrifugal is usually direct driven by an electric motor as is that of the disc separator. Basket centrifugals are made with solid bowls as well as perforated bowls and with stationery plows (see Fig 17.12) for removing the retained solid materials which collects in tightly packed condition within the basket depending, of course, upon the centrifugal force applied.



Courtesy Great Western Sugar Co.

FIG. 17.12. Battery of basket centrifugals used in the refining of sugar.

The force greater than that of gravity which acts to separate solids and fluids of different densities and which is created by a mass moving in a curved path away from the center of curvature of the path, may be analyzed by reference to equations dealing with centrifugal force and the Stokes' equation. The magnitude of the forces is given by the equation:

$$F = Mrw^2$$

where F = force,
M = mass or density of the product,
r = distance from the mass of material to center of rotation,
w = angular velocity in revolutions per minute.

It is thus evident that a greater separating force is obtained under each of the following conditions: (1) greater difference of density between the materials to be separated, (2) higher speed of the centrifugal machine (rpm), and (3) greater bowl diameter.

The rate of milkfat separation is calculated as follows:

It has been shown that Stokes' equation indicates quite accurately the rate of rise of individual fat globules through milk under the influence of gravity. Stokes' equation is:

$$V = \frac{2r^2(d_p - d_f)a}{9\gamma}$$

where V = rate of movement of the fat globule in centimeters per second.
r = radius of the fat globule,
γ = viscosity of the milk serum,
d_p and d_f = densities of the serum and the fat respectively,
a = acceleration.

In the case of fat globules rising under the influence of gravity, a is the gravitational constant and is numerically equal to 980 dynes.

This equation is also used to calculate the velocity of the movement of fat globules through the serum due to the centrifugal force of a cream separator, by expressing a in terms of the acceleration produced by the centrifuge. The equation below gives the value of a, when the acceleration is due to centrifugal force.

$$a = \frac{(2\pi n)^2 R}{(60)^2}$$

when n is the speed of the separator bowl (rpm) and R is the distance of the fat globule from the axis of rotation. The rate of movement of a fat globule through the milk due to the centrifugal force at a given instant is given by the following equation:

$$V = \frac{2r^2(d_p - d_f)4\pi^2 n^2 R}{9\gamma \cdot 3600}$$

Several of the factors in the equation are numbers which may be resolved into a numerical constant of 0.00244. The equation then becomes:

$$V = \frac{0.00244(d_p - d_f)r^2 n^2 R}{\gamma}$$

It is thus apparent that the rate of fat-globule separation is increased by (1) greater difference in density of the milk serum and the milkfat, (2) greater rpm of the centrifuge, (3) greater radius of the fat globule, (4) greater distance from the rotational center, and (5) lower viscosity of the milk serum.

DRESSING

In the foregoing pages, we have discussed various *separating* operations involved in the preparation of raw food materials. Primarily, these were concerned with fruits and vegetables although the principles of the centrifugal separating of milk—an animal product—were given in some detail. Also, in Chapter 14 in connection with the discussion of the receiving operations of the meat packing industry, we discussed briefly the techniques of the "killing floor" or the "killing room." Actually, the methods of dispatching (slaughtering) and dressing involve separating techniques in preparing animal products for their subsequent processing or packing. In reviewing these operations we will also encounter *sorting*, *draining*, *trimming* and *skinning* as well as separating operations related to those already discussed with reference to vegetable products.

To begin with, all meat animals must have the blood *drained* out of the carcass if appearance, flavor, and keeping quality are to be satisfactory. The carcasses must be *sorted* in the interests of quality as well as of public health protection. *Skinning* the carcasses is another prerequisite in their preparation for consumption although some exceptions will be found in the cases of certain animals. *Trimming* is as important in preparing carcasses as vegetable products. *Silking* corn will find a related operational technique in the *dehairing* of hogs, for example. *Eviscerating* will be found to be to animal products what *coring* and *pitting* are to raw fruits.

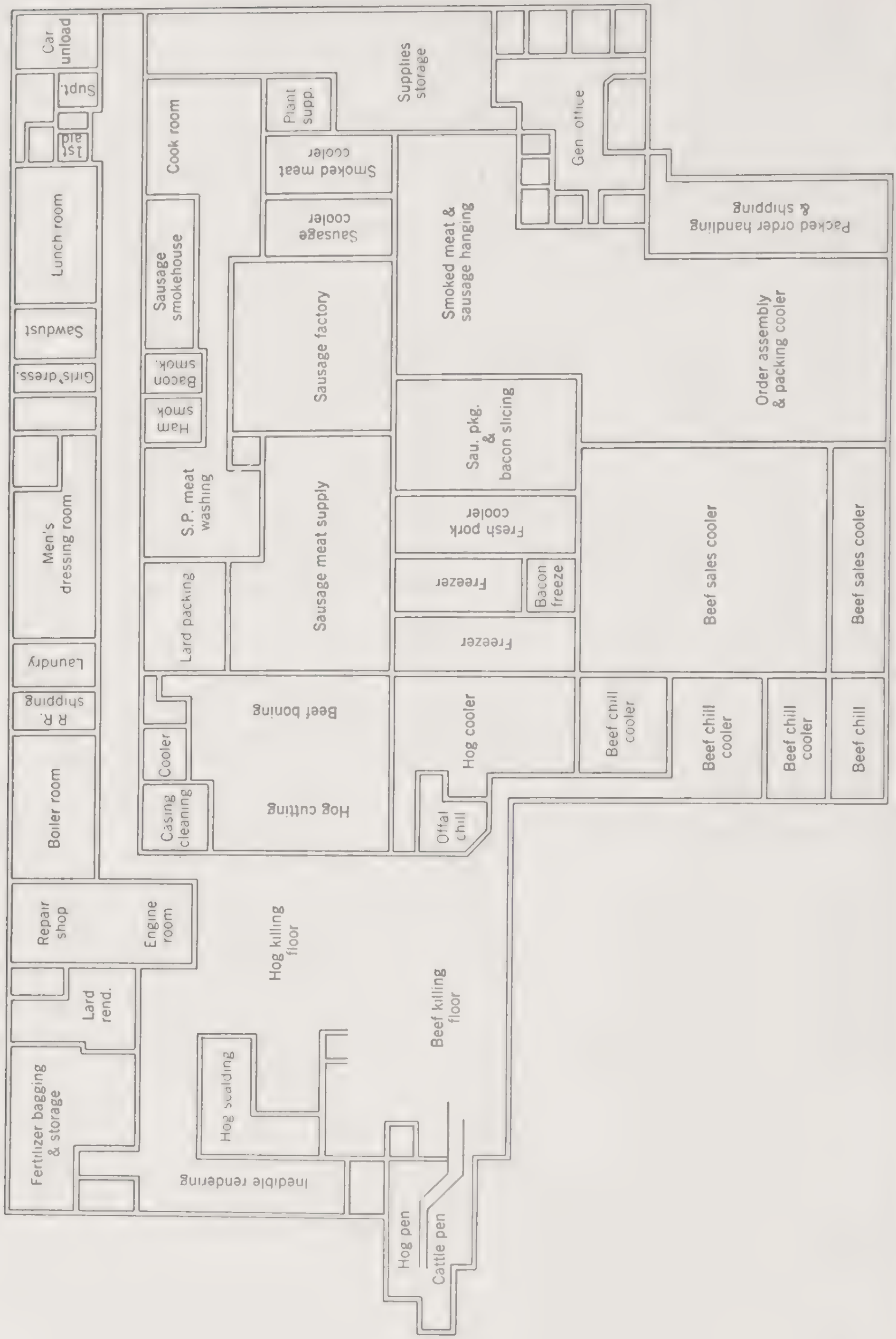
Inasmuch as *dressing*, in its broadest sense, is concerned with all the various individual separating subdivisions mentioned above which differ only in the degree of their application to different animals, we will not further subdivide the remainder of this chapter in their discussion. Rather, we shall use subheadings to designate the *dispatching and dressing* of the different kinds of animals.

Dispatching and Dressing Cattle and Hogs

We will also observe that the methods of dispatching (slaughtering) might be compared basically to the harvesting of vegetable crops. However, in the preparation of the raw animal food materials, dispatching and dressing are so intimately associated that they will not permit of the sharp lines of demarcation so evident in the case of vegetable products. In other words, before dressing any animal food product it is essential that we slaughter the animal and promptly proceed with its preparation in the interests of quality and public health. While we can delay our preparation of certain vegetable foods for varying periods of time before we begin their initial *separating* techniques, animal foods (meats) demand much more expeditious methods and procedures.

Actually, the methods of dispatching and dressing vary with the kind of animal. One of the first steps involves immobilizing the animal either by stunning or anaesthetizing with carbon dioxide gas, as was discussed in Chapter 14. Then, too, in the preparation of kosher meats, certain specialized practices have to be followed.

Since it is more difficult to shackle and "stick" beef animals, as is practiced with hogs, the usual procedure is to stun the animals to insensibility and then to "stick" them. This operation requires considerable skill, as too heavy a blow with the 4- to 5-pound hammers generally used will destroy the skull bones and reduce the value of the brain and may also affect the



Courtesy Braun Bros. Packing Co.

FIG. 17.13. Diagrammatic sketch showing layout of combination beef and port packing plant producing 1,000,000 pounds of finished meat products per week.

bleeding later. On the other hand, if the blow is too light, the animal will not be rendered unconscious. After it has been properly stunned and drops to the floor of the pen, the floor is inclined sufficiently so that the animal slides onto the killing floor. The animal is then shackled by attaching chains to the hind feet and hoisted to a support rail so that it is in a position for sticking and bleeding. A knife is inserted through the median line of the neck where it joins the torso and pointed upwards and through the front wall of the jugular vein; the animal is then allowed to hang until properly bled.

The head is first skinned and then cut free from the carcass. Then follow a series of dissecting operations which separate the head, the feet, and the hide from the carcass. The hide is pulled away and dropped to the floor where it is spread out for inspection prior to grading and removal to a hide cellar. The viscera are dropped into a truck or rolling table directly below for inspection by the Meat Inspection Division of the U. S. Bureau of Animal Industry.[1] The carcass is then split in half by chopping and sawing through the exact middle of the vertebrae. The tail, spinal cord, and sweetbread are removed and the carcass trimmed. The carcass is then washed with water and cloths inserted into the large blood vessels to prevent dripping. At this point the carcass is ready for the chill rooms provided it has passed the B.A.I. inspection. Chilling of beef carcasses is usually accomplished within 48 hours—the quicker the chilling, the less danger there is of spoilage, of course.

Kosher dispatching and dressing of cattle, calves, and sheep, as well as chilling of the beef, lamb, and veal, is governed by certain principles of religious significance and is therefore different in several ways from the methods used by non-Jewish people. In the kosher method, the animals are not stunned but are shackled and hoisted while fully conscious. They are then lowered until one shoulder rests on the floor when a muzzle is drawn over the snout and jaws permitting the neck to be drawn taut and exposing the throat to the cutter. The cutter then skillfully cuts the throat from ear to ear with a special knife and the animal is hoisted to the rail and allowed to bleed fully.

Kosher handling of the carcass subsequent to bleeding is practically the same as otherwise. The kosher cutter examines the animals for adhesions or growths when the breast is opened and again after evisceration. The heart, liver, lungs, and melt are further examined and identified as kosher. The hind quarter is not used, primarily because of the difficulty of removing the vascular tissue, the consumption of which is not permitted according to the tenets of the Jewish religion. All arteries and veins are removed from the fore quarters by the retail dealer before cutting them for trade. Kosher regulations require rapid handling of beef, so that the carcasses may be delivered to the retail shops within 24 hours; consequently rapid chilling is applied. The above description of the kosher method outlines only the barest essentials as there are many details of the rabbinical code which must be adhered to but which are not covered in the above discussion.

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[1] It should be pointed out that this federal agency enforces the Meat Inspection Act of June 30, 1906, amended March 4, 1907 and June 29, 1938 which provides for the inspection and labeling of meat and meat food products entering interstate commerce while that entering intrastate commerce is subject only to local and state regulation or inspections.

We have already discussed in some detail in Chapter 14 the procedures followed in slaughtering hogs in preparing pork products. The shackled hogs are carried to the "sticker" who plunges a two-edge knife into the center of the neck just below the breast bone; the point is directed upward in order to sever the jugular vein in the exact center and also to sever the artery located at this point. This makes a smooth opening about one inch long which permits the blood to flow freely, the hog being permitted to hang from 6 to 10 minutes on the rail to complete the bleeding. When the hog is properly bled, the muscles become limp. Following the completion of bleeding, the hogs are dropped into a scalding tub for the purpose of loosening the hair for easy removal. After scalding at the proper water temperature (usually between 135 and 155°F) and for the proper length of time, the hog is removed from the tub and conveyed to the dehairing machine. A small amount of caustic soda is usually added to the scald water to aid in the removal of scurf.

Dehairing Hogs

There are various types of dehairing machines whose essential properties are to transport the hogs past a series of moving flexible rubber or canvas belts or beaters, upon the ends of which are fastened small pieces of metal or clips, about $2\frac{1}{2}$ inches wide and 3 inches long. The ends of these clips are slightly curved for scraping the hair from the hog. During the dehairing operation, the hog is sprayed continuously with hot water. Upon leaving the dehairing machine, the hog is slitted in each hind leg to permit the insertion of a gambrel stick so that it may be hung head down for further operations. The hogs are then singed to remove any fine, light colored hair not removed by the dehairing machine. Sometimes such hair is removed by a mixture of rosin and oil which is applied to the hog but which quickly solidifies and when removed takes with it any residual hairs. Any hair not removed by the procedure mentioned above is removed by shaving—an operation which requires considerable dexterity.

Following the dehairing operations, the carcass is washed to remove all loose hair and then the head is removed. The carcass is next opened and eviscerated. The viscera including the heart, liver, lungs, large and small intestines, pancreas, spleen, stomach, bladder, and fat coverings or the fat in which the organs are imbedded, are dropped on the table for inspection by the M.I.D. The kidneys, embedded in a pocket of leaf fat, are pressed upward and outward to be left hanging by the "cord" until passed by the B.A.I. inspector, after which they are removed. After evisceration, the carcasses are split down the exact center of the back. The leaf fat, which hangs in the flank of the hog on both sides, is removed next, care being taken to remove the leaf all in one piece. The hams are "faced" at this point in order to provide a more pleasing appearance when they are completely processed.

The carcass is given a final washing following which it is weighed and branded on each of the primal parts with the legend "U.S. Inspected and Passed" and the establishment identification number. The carcass is then ready for chilling which incidentally is one of the most important steps of processing pork. It is essential that the dressed carcass be chilled as rapidly as possible to a point at which bacterial growth will be greatly retarded. This requires normally 18 to 24 hours and the index of its performance is a bone temperature of 32 to 36°F. Hogs shrink in weight during chilling, the extent of which is influenced by such factors as the temperature and humidity of the air, the degree of air movement or circulation, and the dryness of the hogs themselves. An average shrink in 48 hours will approximate 2½ per cent.

Dispatching and Dressing Sheep and Lambs

The slaughtering and dressing of sheep and lambs is somewhat simplified because of the smaller size of the animals. Most sheep slaughtering plants employ a wheel hoist. Particular attention is paid to the application of the shackle at a point just below the toes in order to avoid an unsightly scored appearance of the hind leg, since the hind leg of the animal is one of its most valuable parts. In dispatching sheep, a very sharp, dagger-like knife is inserted into the neck just below the ear so that it severs the jugular vein and other blood vessels in the neck. The animal is allowed to bleed about 5 to 6 minutes before the second operation, skinning, is undertaken. The first step in the dressing of the carcass is that of leg breaking which involves breaking the joints of the foreleg just above the feet. The skinning operation is then commenced with the right hind leg. After making the proper, skillful incisions, the skin is pulled off the back and cut loose from the neck and head as a final step following which the carcass is washed on the outside with warm water.

The first dressing operation consists of opening the breast followed by opening the carcass down the front. Inspection of the viscera by the Meat

Inspection Division usually occurs at this point. The caul fat is removed next, for transfer to the oleo department. The bung, including the entire group of small intestines, is removed and following this, the paunch. The pluck consisting of lungs, liver, and heart is taken out next. Then a small wooden stick about 8 inches long is inserted in the belly of the carcass in order to spread it apart and assist in the chilling. The legs are then crossed; both legs are hung on one hook and the legs are tied for easy handling. The head is next removed and the inside of the carcass washed with water and dried. Some trimming of the carcass is done in order to improve its appearance. The forelegs are folded back in the joint and a skewer is inserted in the back joining the front of the forelegs and fastening them together. This also improves the appearance of the carcass and at the same time saves space in handling. The carcasses are then transferred to the chill room, and when in place, the neck pins are removed, such pins having been inserted in the neck and into the breast in some cases to straighten out the neck and avoid damage to the carcass in handling. The temperature of the chill room is maintained at 32 to 35°F and complete chilling takes usually less than 24 hours because of the relative small sizes of sheep and lamb carcasses. Lamb, incidentally, is marketed as a whole carcass or may be divided before delivery to the retailer.

Dispatching and Dressing Calves

Calves for veal processing are considered largely a by-product of the dairy industry. In order to keep cows producing milk, they must be bred at regular intervals although the raising of such surplus stock may not be economical. While it is not always the case, it is rather common practice to sell half carcasses to the retailer with the skin left on. Therefore, in handling the live calves, great care is taken to keep the animals clean, and in some instances they are bathed just before they are dispatched and dressed. The method of slaughtering is not uniform as some operators stun the calves whereas others do not. Those who shackle and stick without first stunning the animals usually use a wheel hoist similar to that used for hogs and sheep. Because of the relatively light weight of the animals, two calves are shackled on a single shackle and are hoisted simultaneously and dropped upon the bleeding rail.

Ordinarily, sticking is done with a dagger-shaped, sharp, pointed knife. The incision is made at a point in the right side of the neck below the jaw to sever the jugular vein and other blood vessels of the neck. The animals are allowed to hang until bled fully. The calf skin is then washed manually with fountain brushes, or mechanically, using water under high pressure and revolving brushes. Federal inspection does not permit calves with dirty hides to be dressed. The first operation of dressing is the skinning of the head. Then the legs, both front and rear, are skinned and removed at the knee joint. The breast is opened next and the head removed. The opening of the carcass is completed by cutting down with a sharp knife from the crotch to the opening made in the breast. The caul fat is removed and the bladder disconnected. The middle intestines are removed followed by the small intestines and the paunch. The pluck, including the liver, lungs, and heart, is carefully removed since it is a valuable item. The gam holes are marked and the calf hung on a trolley like a dressed hog. The inside of the carcass is then washed and made ready for chilling. Because of their relatively small size, veals can be chilled quickly so that they may be made ready for shipment within 24 hours.

The above outlined procedure is not uniform as in some instances the calves may be skinned warm and a protective coating applied to replace the skin. Skinning of the chilled carcass is also practiced although it is a rather difficult operation. Since the young animals are not protected by the layer of fat one usually finds in mature animals, calf carcasses need a protective coating. Because this fat layer is not present, the flesh surface dries out and the meat loses its normal appearance; consequently, veal is commonly shipped with the hide on or wrapped in a stockinet. Neither method has proved really satisfactory. The so-called "saniseal" process which affords the protection of three coverings or wrappings—a glovetight covering of special cloth, a white parchment, and finally a stockinet—has been successful in effectively preventing drying and darkening of the meat.

Dispatching and Dressing Poultry[2]

The approved method of dispatching involves severing the jugular vein after piercing the brain in the region of the medulla oblongata. This paralyzes the muscles, especially those controlling the feathers, and the bird then bleeds readily. If the cut across the blood vessels is accurately placed, the carcass is readily drained of blood. The cutting of the veins can be made inside the head at the back of the throat or outside the head at the base of the bill if wide enough to sever the two veins, one of which runs down each side of the neck. Instead of puncturing the brain, the use of an electric shock appears to be growing in favor although the current has to be adjusted to the size of the bird to be stunned lest the feather picking be rendered difficult. There is, also, an electrically operated device which severs the jugulars.

As soon as the veins are cut and the brain is pierced, the pulling or re-

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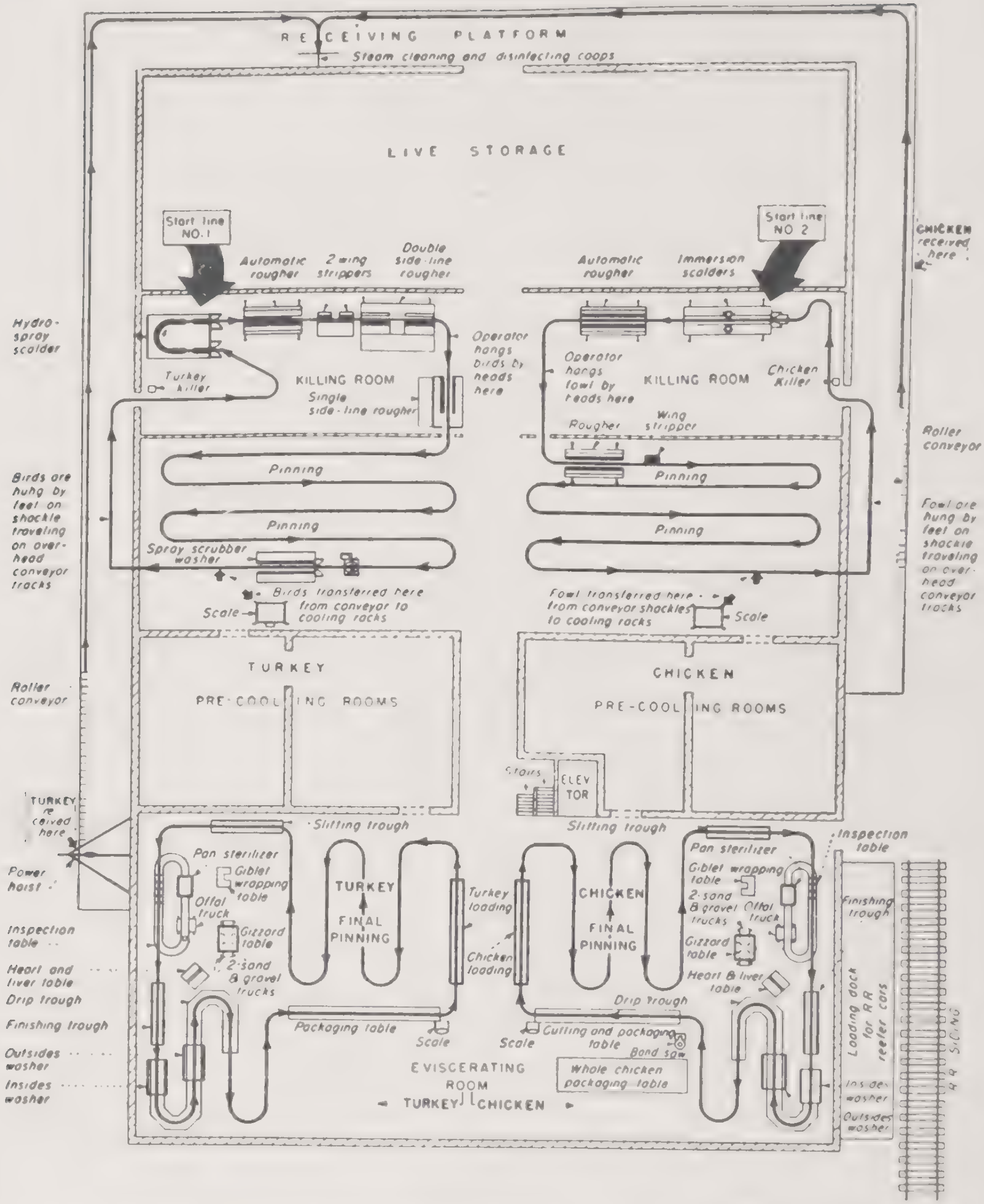
[2] There is a Kosher method of handling poultry requiring the shipment of live birds to market and a special method of killing at the point of sale. Incidentally, the law protects the buyer of any Kosher products in that they must conform to the code, if so advertised.



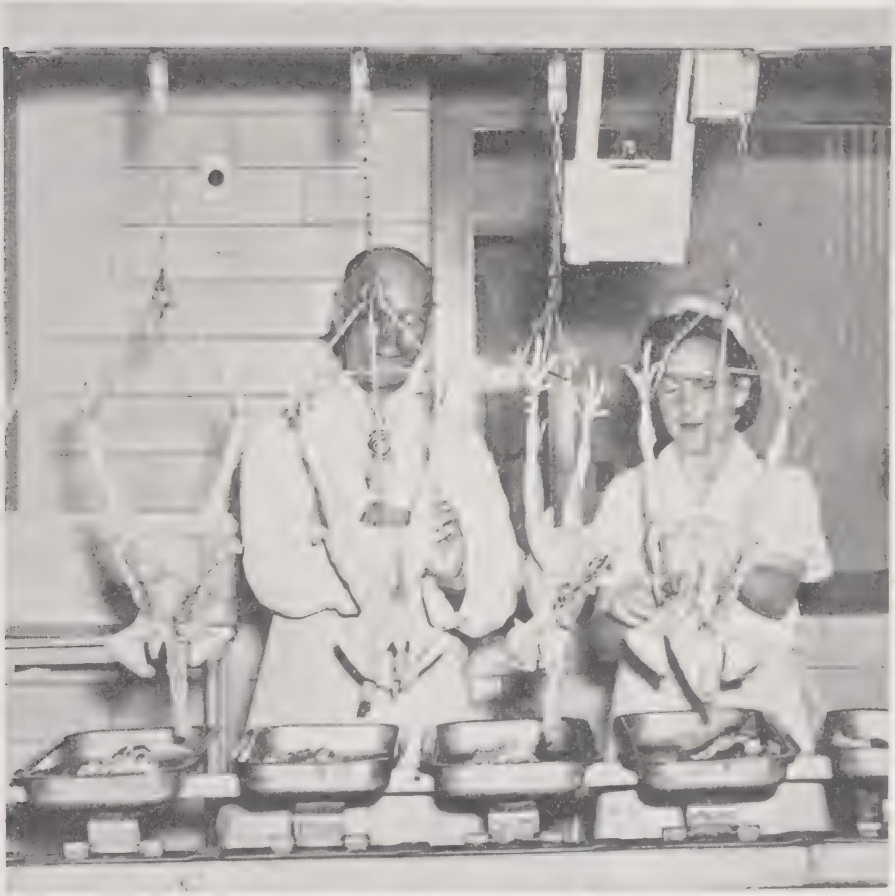
Courtesy USDA-PMA

FIG. 17.14. Diagrammatic sketch showing layout of combination chicken and turkey processing plant depicting rooms for killing, pre-cooling, and eviscerating unit operations.

moval of the feathers begins. The ease with which they come off depends upon the accuracy of the "stick," referring, in the case of poultry, to the accuracy of the piercing of the brain tissue. It was formerly common practice to remove all the feathers by hand, girls generally doing the work after the "rougher" had removed the quills, or heavy wing feathers, and possibly even a few handfuls over the body if the bird happened to be in full feather.

Dry-picked birds are most resistant to decomposition although they are seldom free from tiny feathers and the "pins" about to break through the skin. For this reason, the "semi-scald" process is almost universally used today. After "roughing," the birds are immersed in warm water (128 to 132°F) for approximately 30 seconds, then picked either manually or mechanically. If the killing is properly performed and if the temperature of the water is correct, the feathers are easily and cleanly removed. The semi-scald method must not be confused with the outmoded method of dipping into water heated to 190°F or higher. While this so-called "hard scalding" does make feather removal easy, it shrinks the skin, changes its color, and seriously interferes with the keeping quality.

The increased cost of poultry packing house labor, as well as its scarcity, has stimulated the invention of machines for removing large feathers and



Courtesy USDA-PMA

FIG. 17.15. Eviscerating poultry on conveyor line. Note stainless steel pans below each carcass for holding internal organs. This arrangement permits inspection of both carcasses and internal organs on their way to the packing room.

also the small ones which are time-consuming even though the birds have received a semi-scald. "Wax picking" has become very popular and has been combined with a rubber finger picking machine, by which the dressing of the bird has not only been expedited but the cost lowered with excellent results. After the semi-scald the birds are run through the picking machines which remove most of the body feathers. They are then dipped into a melted wax of special composition and freezing point to form a thin, even coat over the entire carcass. The wax, which sets quickly, is flexible and when stripped off, takes with it the remaining feathers and pins without tearing or scarring the skin as so frequently happens in hand picking. Any fine hairs are removed by singeing. The removal of animal heat is one of the most important operations in the preparation of poultry carcasses for marketing. The birds, immediately after picking, are hung in refrigerated rooms of 30 to 32°F and within 12 hours the carcasses will have been sufficiently chilled if the temperature of the cooler is maintained at 32°F during the cooling period. The quicker the animal heat is removed, the better, but it is not desirable to cool below the frosting point of the flesh until after the bird is graded and packed in its container.

The removal of entrails from the body cavity of a chicken is not quite as simple as it might appear. The delicate membranes lining the body cavity are extremely susceptible to bacterial invasion. Therefore, since it is not possible to eviscerate under aseptic conditions, immediate freezing is widely employed for preservations. However, frozen eviscerated poultry is increasing in favor rapidly. Fast freezing is especially desirable in any case. Also, desiccation must be most carefully guarded against. Sanitation in poultry packing houses where eviscerating is done on a large scale is a matter of rigid inspection. Giblets are removed with a minimum of tearing, placed on perforated trays, and washed with a gentle spray of water. The carcass is thoroughly washed under sprays of cold water and then wrapped and packaged whole, or, in the case of fryers, cut in the usual manner.

Dressing Fish

Fish are prepared in a variety of ways; *whole or round*, in which case the fish are not dressed in any way; *gibbed*, whereby the gills and viscera are removed without slitting the belly cavity; *eviscerated*, in which the viscera are removed by slitting the belly cavity but leaving the gills intact; *dressed*, with removal of the head, fins, tail, and viscera; *split*, where the fish has been split down the backbone and the head and viscera are removed, the two halves being held together by the belly wall which is intact; *filleted*, when the flesh is cut into two boneless strips one from each side and either with or without the skin removed; *butterfly filleted*, where the two fillets are left adhering together at the backbone; and *steaked*, when sliced at right angles to the backbone and cut in cross-section slices of about one-half inch thick.

Fish are usually packed directly in some kind of crushed ice, the amount depending on the climate and distance to be shipped. Fillets or steaks are usually packed in tin or wooden containers of 10- to 25-pound capacity. Whole fish are usually packed in large wooden boxes of crushed ice although in some cases, barrels are still used. One-pound cartons of fast-frozen fillets have introduced salt water fish in prime condition to residents of our interior areas with growing acceptance.

18. Disintegrating

The breaking up, or distortion, of food particles into fragments is termed *disintegration*. The operation may be accomplished in various ways. Incidentally, the student must not expect too much consistency in trade terminology. At times, the operation is named in accordance with the mechanical principle involved, while in other instances, the nature of the end product determines the name applied to the machine. Again, we would emphasize that basically *a unit operation is concerned with the physical means to an end*.

Disintegrating, considered as a unit operation, is involved in the preparation of raw food materials for their subsequent processing. Here it is again evident that unit operations overlap each other, for during the disintegration of foods by cutting, grinding, pulping, and milling, products are again sorted with rejection of the underdeveloped, damaged, or overripe. With some products, even a third and fourth sorting is made—especially when the product is packed into containers. While the advantages of certain separating operations are too obvious to be debated, it should again be emphasized that during the preparation, processing, and packaging of foods sorting is progressively and effectively practiced in most food industries. It is generally conceded that the quality of any final product depends largely upon the effectiveness of (1) its initial grading and (2) its subsequent sorting. In the latter case, where it can be continuously carried out in conjunction with other unit operations, its performance will be correspondingly more efficient.

It was stated earlier that the primary objective of all industrial food operations is the conservation, or preservation, of foods by such means as will assure the ultimate consumer optimum quality at minimum cost. Strange as it may seem, disintegration as a unit operation is one that extends the conservation, or preservation, of foods. In fruit canning, for example, there is almost always a certain quantity of good, strictly edible but waste, fruit which is graded out as not being suitable for canning. Such so-called waste fruit (and the term is apt to be misleading for it refers to all material not going through the main processes) may be utilized in a number of ways: (1) crushed, packed, and sterilized for bakers, confectioners, etc.; (2)

pulped, concentrated, sweetened, and packed for ice cream, etc.; (3) pulped and sold as such; (4) pulped and converted into jams, etc.; and (5) pulped and used in the preparation of flavors, fruit acids, etc. Therefore, in the conservation of such nutritious food materials, we have to rely heavily upon disintegrating operations which produce considerable change in form and consequently comprise another important group of food preparation unit operations.

CUTTING

Strictly speaking, *cutting* is an operation involving the dividing, or subdividing, of a food material by means of a sharp-edged instrument. Various cutting devices are available. The name of the operation is not necessarily associated with the manner of accomplishing the subdivision, but with the size or shape or the product.

Where cutting machines are used, they are usually constructed of stainless steel or "Monel" metal. Rotary cutters generally consist of heavy-hardened alloy steel rotary knives operating in a cast body, one side of which is readily opened for adjustment, sharpening, and cleaning. Rotary cutters normally will cut, granulate, or shred to any desired size.

Meat Cutting

Just as in Chapter 17 we outlined those separating operations involved in the dressing of animal products, we have corresponding disintegrating operations in preparing meat cuts as well as fancy meats, casings, and sausage. This particular section will be concerned with the cutting operations required to reduce carcasses to the primal parts.

Beef Cutting

Two separate and distinct operations are involved in beef cutting, the applications of which depend entirely upon the quality of the beef itself. High-quality beef finds its best markets as fresh beef, ultimately in the form of retail cuts. The degree to which a meat packer "breaks down" a high-quality carcass depends to some extent upon its policy and its trade outlets. In a few instances, beef may leave the packing plant as sides, but more often as quarters, or in the form of wholesale cuts. Normally the cutting required to produce the retail cuts is done by the retail meat dealer. The lower quality beef commonly is termed "cutter" or "canner" beef, but more accurately should perhaps be called "leans" since such beef is produced from cattle which are marketed in the unfattened state. Usually it cannot be marketed as fresh beef in the form of retail cuts. These beef carcasses are separated into the primal parts at the packing plant and in addition are boned. The boneless cuts are used either in sausage or canned meats or as dried and smoked beef, or are cured.

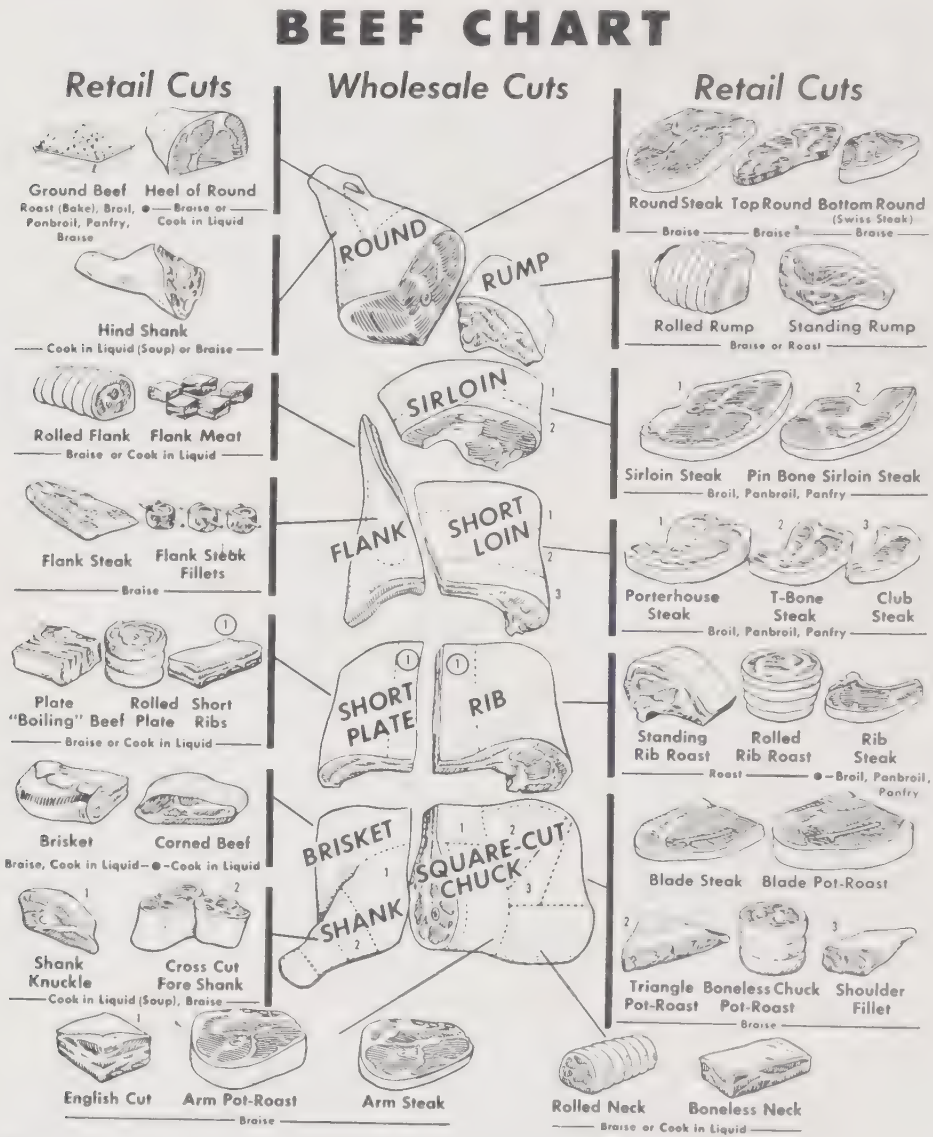
After chilling, the first disintegrating operation, while the carcass is still hanging, is to quarter it, that is, to halve each side, the cut generally being made so as to leave one rib on the hind quarter. Reduction of the forequarter into the primal parts is then accomplished. The chuck and rib are sawed from the full plate and then the rib is separated from the chuck. The full plate may be divided into the short plate, brisket, and shank. In reducing the hindquarter to its primal parts, the hanging tenderloin, together with the kidney and kidney fat, is first removed. Next the flank is taken off, the remainder being cut into two pieces making a loin and a round with rump attached, the round and rump then being separated. There are some definite descriptions assigned each primal part which will not be outlined in further detail. The various beef cuts will be found illustrated in Fig. 18.1.

Pork Cutting

The cutting of pork is more complex than that of other meats, since it involves not only the ordinary factors of quality (e.g., proportions of fat and lean, weight, etc.) but also the styles of cutting and methods of packing by which it is prepared for different classes of trade. No attempt will be made here to describe the various grades of pork cuts, as such detail is not essential in discussing the incidental disintegrating unit operations.

The temperature at which hog carcasses are brought out after being chilled varies with the individual plant practice, usually ranging from 32 to 38°F. These temperatures are sufficient to arrest bacterial development and harden the meat for easy and accurate cutting. Knives used in cutting are dipped into hot water immediately prior to use in order to facilitate cutting, especially through hard chilled fat.

From a materials handling viewpoint, a modern pork-cutting floor is well designed and makes use of many mechanical devices that will perform the cutting operations efficiently and rapidly. The hog carcasses are usually brought from the cooler by a conveyor, and are dropped on a moving table by the mere act of cutting the gam strings. The moving table conveys the carcass past an operator who saws the bone with a mechanically driven saw, permitting the ham to be cut off. The ham is slid to a band saw, where the foot is cut off. The rest of the carcass proceeds to the second station, where the shoulder is chopped or cut off. After the shoulders are thus detached, they are conveyed to a band saw which cuts off the butt. Neck bones are next lifted, and the neck is trimmed. The picnic or shoulder ham is then cut out, followed by the jowls. After this, a cut is made through the ribs for the entire length of the side and on a line from the inside edge of the tail bone to the inside tip of the back bone on the shoulder end. This permits easier loining, which is the next operation. Loins are pulled by drawing a two-handled knife through the side between the loin and the fat. After



* Prime and choice grades may be broiled, panbroiled or panfried

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FIG. 18.1.

the sides have been passed through a roller to press them flat, they are rubbed. The fat back is removed from the belly, either manually or mechanically. The belly is trimmed to size and subsequently converted to bacon through curing and smoking. The fat back, if intended for the manufacture of lard, may be skinned. Often, bellies are skinned prior to cutting.

Following the pork-cutting operations, some cuts require additional trimming which are separating unit operations in themselves. Hams are frequently partially skinned or boned. Loins are often boned, and many of the

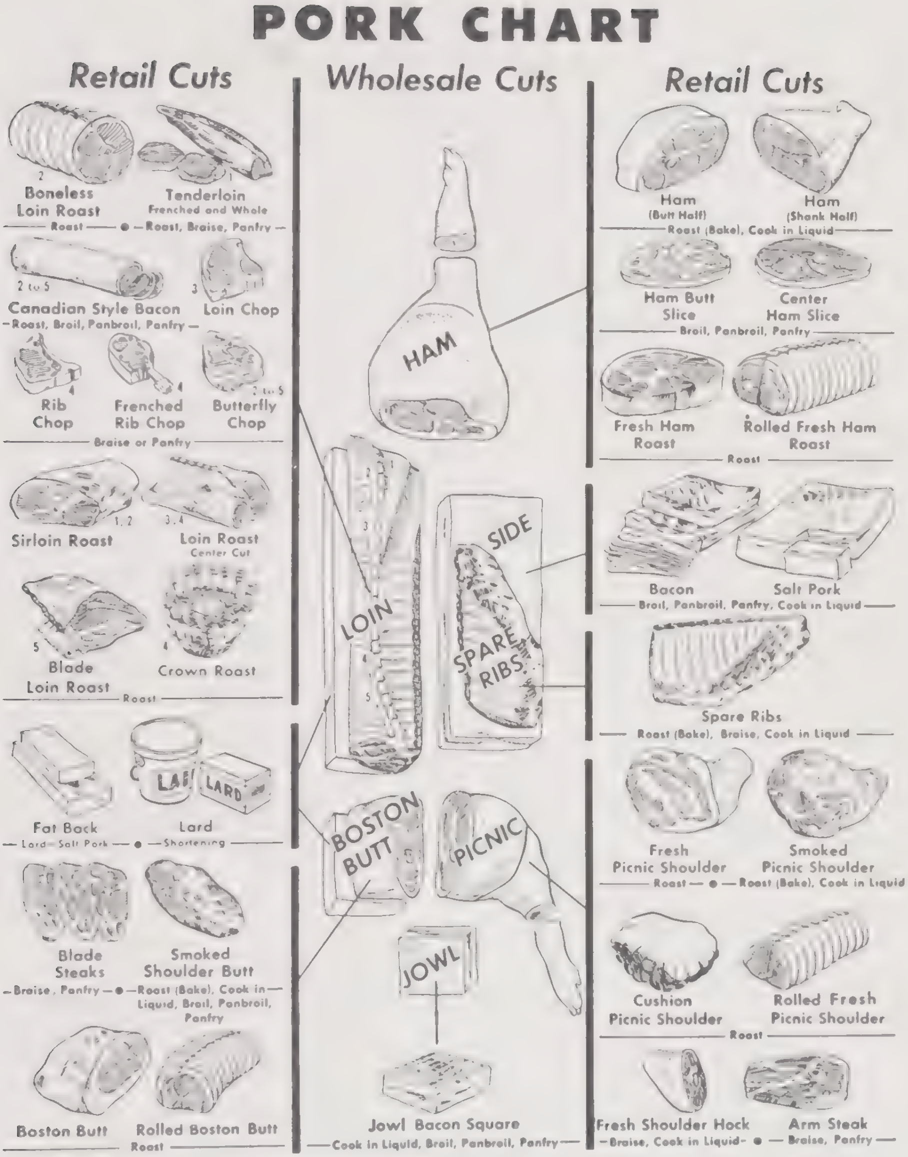

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Fig. 18.2.

cuts receive additional trimming. The small pieces of meat obtained in such manner are utilized in the manufacture of sausage and other table-ready meats. The various pork cuts are illustrated in Fig. 18.2.

Specialty pork items are usually handled separately and include tongues, brains, chitterlings (intestines), spleens, plucks, (liver and heart), giblet meat (fleshy portion of the diaphragm muscle), kidneys, pigs' feet, and pigtails.

Lamb Cutting

Lamb cuts may be prepared before delivery to the retailer or the whole carcass may be marketed. The various cuts obtained from lamb and sheep carcasses will be found illustrated in Fig. 18.3.

Veal Cutting

Veal cuts, like lamb cuts, may be prepared before delivery to the retailer or the whole carcasses may be marketed. The various cuts obtained from a calf carcass will be found illustrated in Fig. 18.4.

Poultry Cutting

Inasmuch as poultry are usually prepared as carcassses there are no particular cuts involved in their preparation for subsequent marketing or processing except in such cases where "drumsticks" or breast slices are offered. A more recent development has been that of poultry meat slices and fragments processed into uniform pressed portions of representative sections of various birds in order that food purveyors such as hotels and restaurants might offer diners uniform portions. This also has economic advantages in the fact that uniformity of portions might be better controlled in the actual meal preparations.

Fish Cutting

The various fish "cuts" were simultaneously described in Chapter 17 in the discussion of the various methods of dressing fish.

Fancy Meats Preparations

Included under the term "fancy meats" are hard meats, sweetbread, tongue, heart, liver, spleen (melts), tripe, kidney, oxtail, pigtail, and many other items of similar nature. As a class, these items may be described as organ rather than muscle meat although that description does not apply to all those mentioned above. Normally, fancy meat products are more perishable and require more attention than regular meat products. Following are the operations by which the more important fancy meats are obtained.

Head meats include hog heads which are processed immediately after removal from the carcass on the killing floor. Those which are not to be marketed as whole heads are cut into skull fat for lard; ears, snouts, lips and tongue for sausage or for curing; cheek, head, and jaw meat for sausage; brains to be sold fresh or frozen; and jaws and skulls for lard, grease, and glue.

Beef heads are cut free from the carcass and upon passing M.I.D. inspection, the tongues are removed. Head meat is removed mainly for use

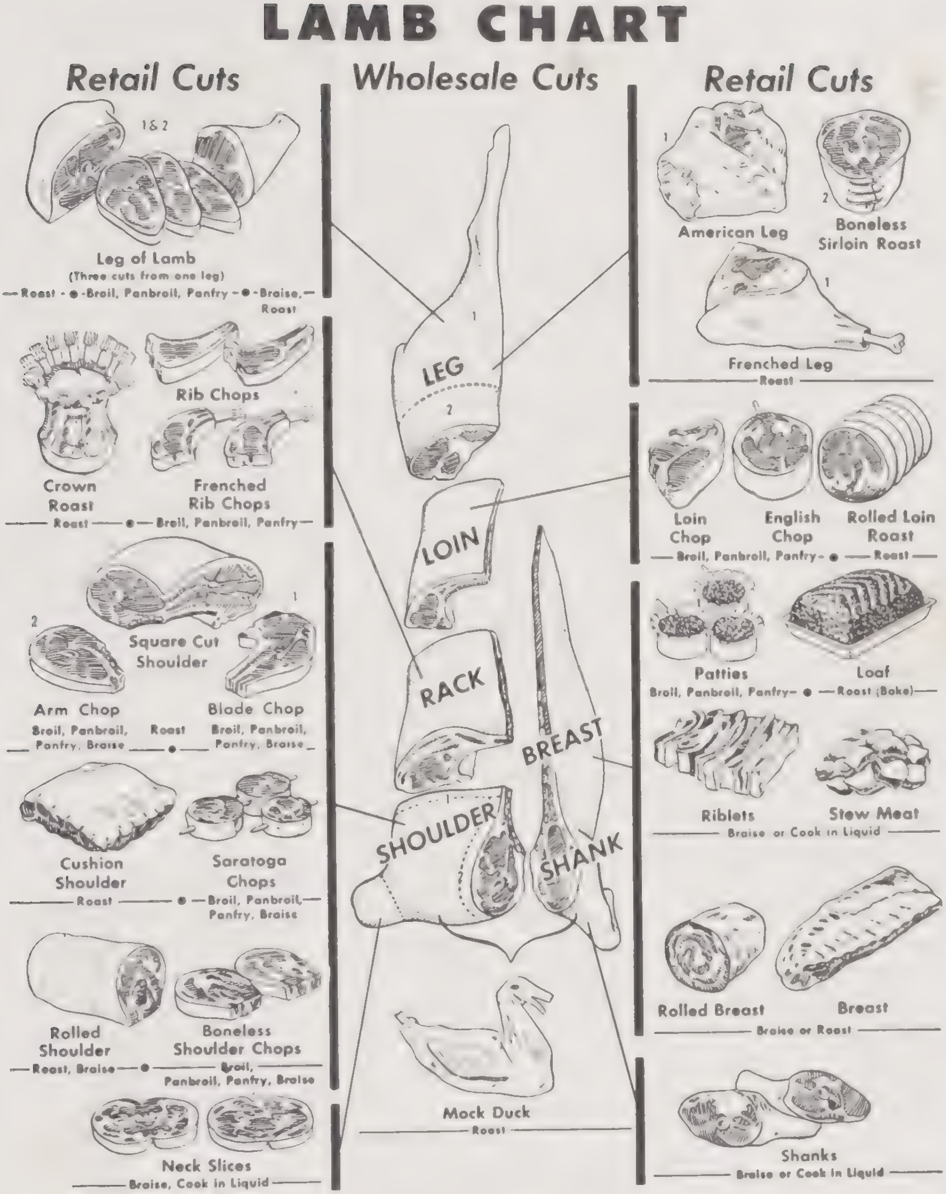

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Fig. 18.3.

in sausage and other table-ready meats whereas cheek meat may be used fresh or cured for sausage or sold to retail markets or to canners—the head is then split and the brains removed and washed. Sheep heads after removal from the carcass are washed, and the tongues removed. Cheek meat is trimmed off as well as any other meat present on the head; the head is then split and the brains removed, the remainder of the head being sent to the

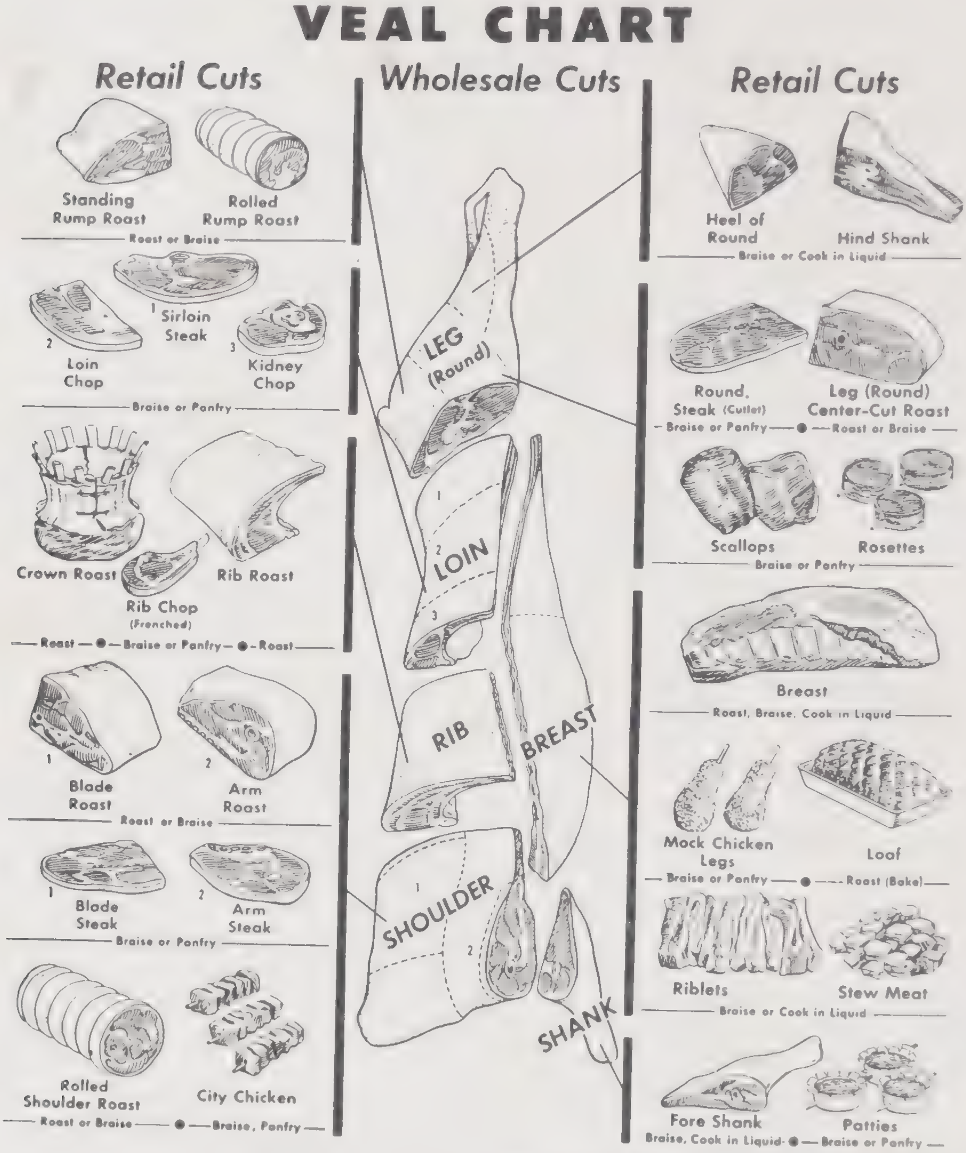

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FIG. 18.4.

tanks either for tallow and glue or tallow and bone meal. Unless the calf heads are chilled and sold as such, they are thoroughly washed after skinning, the tongues removed, and the cheek and other meat trimmed out; the skulls are then split and the brains removed, the remainder of the head being disposed of as inedibles.

Livers include "pig" liver, beef liver, lamb liver, and calves' liver. Livers are removed from the hog with the pluck (trachea, esophagus, liver, heart, and lungs) and after M.I.D. inspection are hung on tinned hooks or racks and rapidly chilled; those from beef cattle are removed from the carcass after the small intestines have been taken out and generally are cut across the thin border or lower extremity of the liver so that, when hung, any excess blood drains out. Livers from sheep are removed with the pluck and are carefully trimmed, washed, and hung upon racks for chilling; calves' liver is also removed with the plucks and is especially prized.

Plucks include those from hogs, beef cattle, sheep, and calves. The hog pluck consists of trachea, esophagus, liver, heart, and lungs, and is separated from the rest of the viscera after removal. The gall bladder, liver, heart, lungs, and giblet meat are trimmed off in succession and separated. The gall or gall bladder may be used in the manufacture of pharmaceutical supplies, the trachea for rendered pork fat manufacture. The esophagus contains a muscle called weasand meat which is used in the manufacture of sausage. The lungs are considered inedible. Hearts are sold as such or are used in prepared meats. The giblet meat is the fleshy portion of the diaphragm muscle. Commercial hog pluck consists of the heart and liver.

Beef plucks which consist of heart, lungs, and trachea, are separated. The hearts go into the retail trade either as fancy meats or prepared meat products. The trachea proper is not used for food except as a possible source of tallow; the lungs may be used for edible purposes but are also converted into tankage.

Sheep plucks consist of lungs, liver, and heart. It is frequently sold with all parts intact whereas when separated, the hearts may be converted into prepared meats, the lungs go to tankage, and the livers are chilled and sold as such.

Calf pluck is especially prized because it contains the liver. Sweetbreads are also included in this pluck and are considered a special delicacy. Sometimes, the calf pluck is sold complete including the liver, lungs, and heart; if it is divided, the liver is sold fresh, the lungs are converted to tankage, the heart is chilled and used either for sausage or as a fancy meat, and the sweetbreads are marketed either fresh or frozen.

Tails include pigtails which are cut from the carcass on the cutting floor and shipped without further processing, and beeftails (or oxtails) which are handled carefully to avoid bruising and discoloration to be marketed fresh or frozen or to be used in canning.

Tripe is prepared from the stomachs of cattle. These are rinsed in water and freed of their contents, and placed in a revolving washer to which has been added some sal soda for removing the mucous membrane. The stomach is then cooked for several hours and sold "as is" or may be cured.

Kidneys of hog, cattle, sheep, and calves are handled similarly although they are usually sold in the carcass. When they are removed from the carcass, they are promptly chilled and sold without further processing.

Sausage usually consists of chopped meat seasoned and placed in casings, which are chiefly sheep, pork, and beef. A wide variety of meats is used in the manufacture of sausage and table-ready meats. In some cases, the entire carcass of meat animals is used whereas in other cases, certain cuts or trimmings not in great demand for other uses are employed. The principal meats used in making sausage are beef and pork, to which may be added certain other ingredients such as salt and spices, cereals in limited amounts such as corn flour, potato flour, rice flour, and wheat flour (soya flour is not permitted) and even a small amount of dry skim milk. The processing of sausage classified this type of product into six groups: fresh, smoked, cooked, smoked and cooked, semi-dry, and dry. We are not concerned with the processing details and therefore will not review the various techniques and compositions. However, in addition to the general regulations pertaining to meats, there are some special M.I.D. regulations which apply to sausage. From the food-engineering standpoint, sausage may be defined as a variety of meat products containing the ground, chopped, comminuted, and otherwise variously disintegrated products of various meat cuts and fancy meat preparations.

The use of *casings* in the making of sausage and other table-ready meats is an old practice. There has developed over years past a necessity for cleaning, curing, and storing a surplus of casings sufficient for the needs of the meat packing industry and of individual sausage factories which have no dressing operations. There are some meat packing plants that do not cure their casings but sell them "green" directly to casing dealers and processors.

Hog, beef, and sheep casings are prepared and cured for many different purposes and include a number of internal organs which are processed and cured in a variety of ways depending upon their source. Sheep casings are among the most valuable parts of the sheep and are especially favored, in part for their tenderness and in part for their size, which varies in diameter from approximately $11/16$ to $15/16$ inch and over.

Cellulose casings have come into use in more recent years and are made by regeneration of cellulose in the form and size desired. Cellulose casings ordinarily are tough and, unlike natural casings, are usually not eaten. When cellulose casings are used in the manufacture of frankfurts, a skin of coagulated protein forms under the cellulose during the smoking and cooking. Consequently, the cellulose casing can be removed and a "skinless" frankfurt is the result.

Slicing

As an example, where a thin, sharp, rapidly operating blade cuts thin pieces of meat from a cooked ham, the operation is referred to as slicing. The same technique is employed for slicing fruits, vegetables, bread, and cheese. There is a mechanism for holding the bulk commodity to be sliced, and an adjustment for varying the thickness of the slices.

The cutting of pickles lengthwise into quarters or halves is also a slicing operation. A unique feature of this machine permits the knives to follow the contour of the pickle. Thus a curved pickle receives a curved cut, resulting in a uniform product. The pickles are fed from a hopper into a tube. They next drop into a set of four round belts which feed them to the knives. These belts run on wheels mounted on equalizing levers to permit pickles of different diameters to remain centered with the knives for their entire length. The knives are circular and rotate to slice to the desired size.

The peach slicing machine consists of several circular, revolving knives above a rubber belt on which the halves, cup side down, are conveyed. A vibrating screen automatically places most of the peach halves in the proper position for slicing. Pineapples, after coring and trimming, are automatically cut into circular pieces by the knives of the slicing machines.

Chipping

The operation of cutting or breaking small portions from a large piece of food material is known as chipping. In the food field, chipping equipment is used to cut citrus peels. The machine used resembles a lawn mower. A number of blades are mounted spirally across a roller and revolve at 30,000 to 32,000 rpm. Originally, the machine was fed manually but later models use an automatic belt onto which the product is thrown. The thickness of the cut is determined by the numbered change wheels which can be adjusted readily.

Dicing

Dicing, or cutting into cubes, is accomplished automatically at varying speeds up to 2½ tons per hour. From hoppers, vegetables are sliced on to a rapidly moving conveyor belt. The slices are transferred to a series of knives which cut them into strips. These strips then run through circular knives at right angles, converting them into cubes.

A machine generally referred to as a silent cutter is extensively used in preparing meat for sausage. The machine consists of a shallow bowl raised at the center. The bowl is mounted on a vertical shaft so it may rotate in a horizontal plane. An assembly of pickle-shaped knives, mounted in a vertical plane, rotates at high-speed within the area between the raised center and the sides of the bowl. The knives are set to clear the bowl bottom by a fraction of an inch. As the bowl rotates, meat, fish, or other material is carried under the blades which cut it into fine particles.

Machines are available for cutting corn from the cob for either cream style or whole kernel pack. A double rotary head provides an opportunity to run either style mentioned. For cream style, the first rotary head is equipped with knives and depth gauges, the second head with scrapers. For whole kernel corn, only the first head is equipped with knives to make a single cut. The ears are forced through the circular knives small end first. Position of the knives is varied by springs according to the size of the ear. The knives are readily removed for cleaning and sharpening.

Shredding

Shredding is the operation of tearing or cutting a food into tiny fragments, grating being the term more strictly reserved for the incidental tearing or disintegrating technique.

Cabbage is shredded by cutting on a machine of such size that an operator can be accommodated on each side. Four cabbages are shredded simultaneously and continuously. A series of hard tempered, long circular knives are mounted on a flat rotating disc. At 150 rpm the machine will produce 40 to 50 tons of fine, long-cut cabbage preferred for kraut manufacture.

Grating

Grating of horseradish, coconut, cheese, and vegetables is accomplished by having the food in question impinge against a roller on whose surface are embedded shallow knives.

Chopping

Chopping is a type of unit operation involving the cutting of a food by repeated blows. The product obtained consists of pieces or chunks similar to those obtained in a true chopping operation.

One type of mechanical cutter is fed a continuous stream of whole tomatoes at any rate up to 25 tons per hour. The tomatoes pass through a hopper into a crushing cylinder where a screw forces the fruit through equally spaced openings. A rotary blade cuts the crushed tomatoes into uniform pieces as they pass through the grid. A pump removes the juice and fine solid material. For tomato juice manufacture, a three-blade cutter is employed. Stainless steel construction of all parts coming on contact with the tomatoes insures a bright colored product, easy sanitation, and a minimum of corrosion.

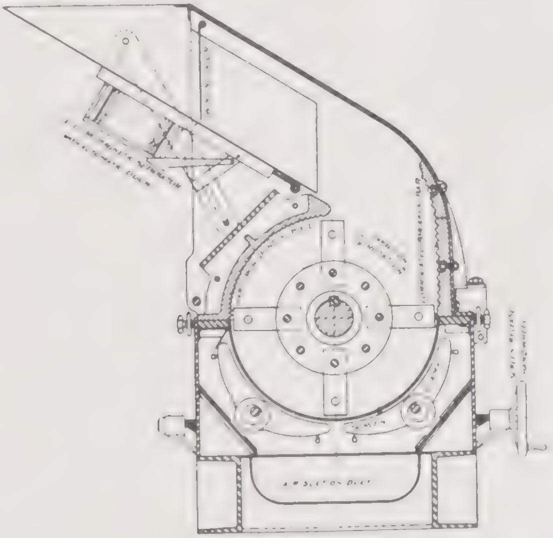
Another well-known chopper cuts pumpkin, squash, root vegetables, and oranges for marmalade, into chunks $\frac{1}{4}$ x $\frac{3}{8}$ inch. The machine consists of a heavy frame supporting two bronze disks keyed to a steel shaft which travels in ball bearing pillow blocks. Each disk carries three stainless steel knives which cut alternately, thus equalizing the strain and reducing the power required. Capacity is about 6 tons per hour.

The so-called meat chopper (or grinder) found in every home is the prototype of an important commercial food cutter. The body is a metal casting with a rifled interior. Within the cylinder is a worm which revolves in a horizontal plane to push the foot forward. At the exit end of the worm is a rotary knife, followed by a perforated plate. The size of the perforations, and their shape, permit a variety of products. By providing the user with a series of plates, the manufacturer greatly increases the utility of the machine.

GRINDING

Grinding is the unit operation of reducing particle size. Used in this sense, the term becomes generic, but grinding is also used to describe specific techniques. When the commodity is hard, such as the wheat berry, the size reduction may be accomplished by the use of crushing and friction. When the material is soft and fibrous, like meat, and major operation involves cutting and tearing.

Such materials as spices and grains are frequently ground in hammermills. A hopper permits feeding by gravity. The solid material is fed to a hard breaker bar with grooves in the surface, forming the upper half of the bowl. Hard steel plates rotating within the bowl, and set for the proper clearance to give the desired fineness, crush the grain or spice against the grooved grinding plate. The lower half of the bowl is provided with a removable screen to permit the fines to pass through (see Fig. 18.5).



Courtesy Robinson Mfg. Co.

FIG. 18.5. Hammermill sectional view showing arrangement of hammers, breaker bars, grinding plate, screen, screen clamps, and release.

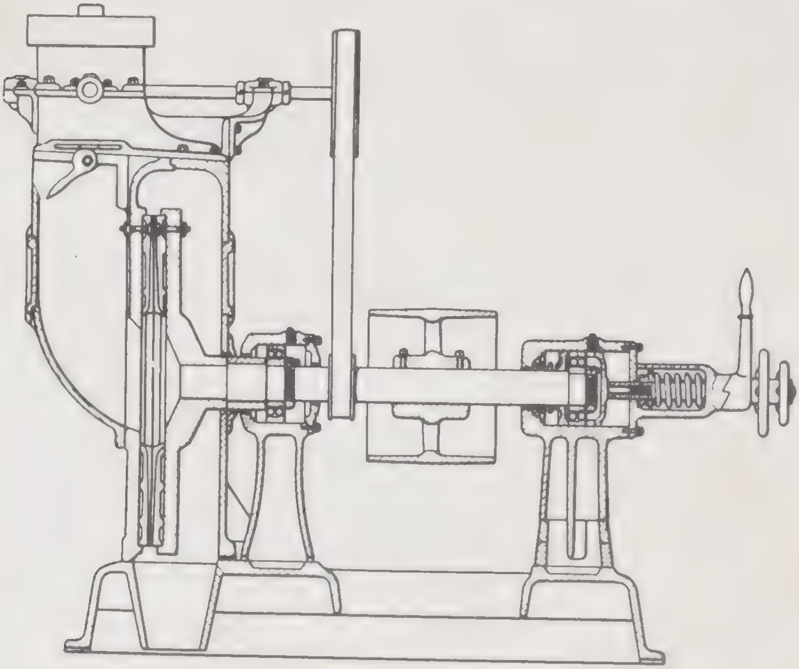
Milling

Grinding by friction is well exemplified by attrition mills of which there are several types. All are provided with a hopper for gravity or worm feed and revolving steel cutters.

In the single disk attrition mill, the solids are fed into a gap formed by a vertical, revolving, grooved steel plate and the grooved steel surface of the mill body. When the plates revolves at high speed, the solid material falling into the gap is torn apart. The gap is adjustable to provide any degree of fineness (see Fig. 18.6).

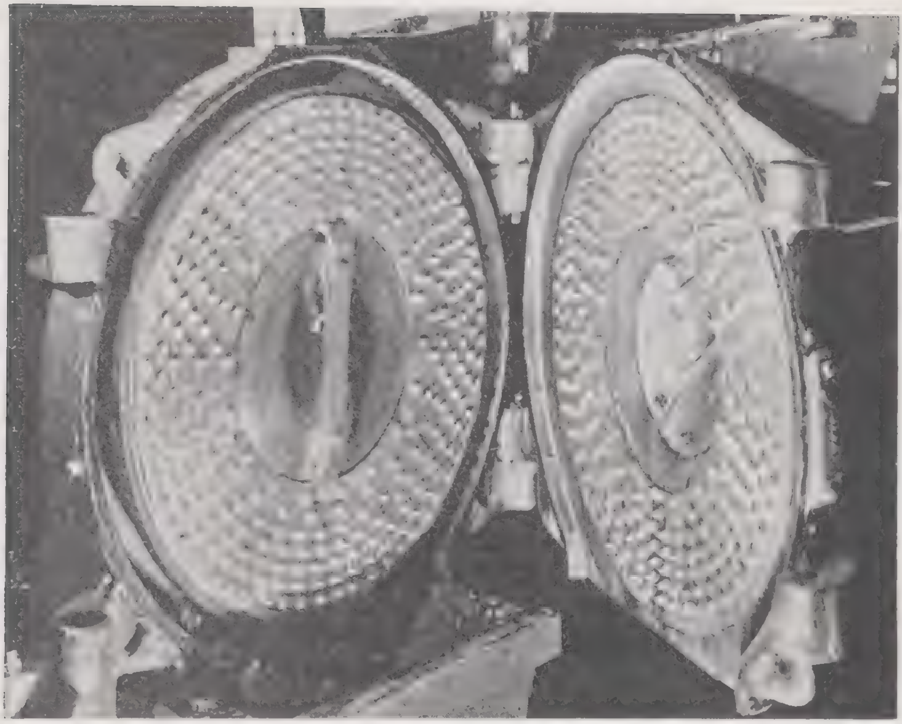
The double disk attrition mill has two radial, or helical, grooved steel plates revolving in opposite directions. An adjustable gap provides an opportunity to control the degree of fineness.

The roller mill is extensively used in the conversion of wheat to flour. This type grinder consists of corrugated hardened steel rollers 9 x 30 inches running in pairs and toward each other. The speed differential is usually 2½ to 1. The rolls are mounted with compression springs to permit large



Courtesy Robinson Mfg. Co.

Fig. 18.6. Single runner attrition mill. The sectional view indicates the general assembly and principle of operation. Feed flows by gravity into the center of the stationary plate which is bolted to hinged housing. Ground product discharges through hopper at base of mill. Ball bearings are enclosed in dust-proof and oil tight housings finished with split caps for assembling convenience. Hand wheels at end regulate air gap between plates. Separating spring prevents plates from drifting together.



Courtesy Corn Industries Research Foundation.

FIG. 18.7. Degerminating mill. The studded rotary plates which turn in opposite directions tear the steeped corn kernel apart without crushing the germ.

hard objects to pass yet return the rolls to their original position without disturbing the grinding adjustment. The top pair of rolls has 10 to 12 corrugations per inch, somewhat spiraled, the wheat passing through being known as the "first break" (see Fig. 5.4, Vol. I). Each successive pair of rolls carries smaller corrugations until the fifth break with 26 to 28 corrugations per inch, when they become smooth and are known as reduction rolls.

In the milling of corn, following the steeping treatment, the corn is passed through a Foos Mill. This is a type of attrition mill designed to free the germ without crushing it, loosen the hull, and disintegrate the endosperm. The Foos Mill consists essentially of studded plates rotating in opposite directions (see Fig. 18.7).

Buhr Mills are used to separate the starch, gluten, and hulls in the wet milling of corn. Buhrstones are 4 to $4\frac{1}{2}$ feet in diameter and about one foot thick. They are made of carefully selected stone of a siliceous nature. Coarse corrugations are cut near the center with finer corrugations running diagonally to the outside edge. Both stones are mounted horizontally, one above the other. The material to be ground (in the form of a slurry) passes between the gap while the stones are revolving, thus reducing the size of the particles (see frontispiece in Vol. I, upper right-hand corner).

The buhrstone mill was used almost exclusively prior to the development of the steel roller mill for the manufacture of flour. It is still employed as outlined above and for the manufacture of a small amount of cornmeal.

Chocolate liquor (bitter or baking chocolate) is made by grinding cacao nibs on buhrstone mills. Milling, as the grinding of chocolate is called, has for its purpose the reduction of particle size to obtain maximum smoothness. Poor grinding not only does not produce smoothness, but gives low cacao butter yields, and a cocoa powder of poor suspension.

The buhrstones used in milling chocolate are preferably of French origin. The horizontally mounted stones are dressed by having grooves cut into the surface to increase the grinding effect. The lower stone is stationary while the top stone revolves. As a result of friction, heat up to 40°C is developed. This melts the fat causing the entire mass to become fluid.

A coarse grind can be obtained by using a hammermill type of machine. This promises high production and is frequently used as a preliminary to buhrstone milling.

Melangeuring

This is a term used exclusively in the chocolate trade to describe a type of grinding by rolls, the object of which is to mix various ingredients with the chocolate. The melangeur is essentially a chaser mill consisting of two granite rollers that ride on a rotating steel or granite bed heated by steam.

Conching

The third step in preparing a high-grade chocolate is termed conching. This is a kneading action produced by a rolling pressure, the purpose of which is to increase the smoothness and flavor and to stabilize viscosity.

The machine is a pot-shaped vessel with a concave bed of steel or granite. The tank contains a roller which is driven back and forth by an eccentric. This rolling action continues for long periods of time in an effort to obtain absolute uniformity. With a jacketed vessel it is possible to heat with water or steam to any desired temperature.

Refining

This is the fourth step in the reduction of particle size of chocolate. Properly done, particles are colloidal after refining. This operation is affected by passing the chocolate over five smooth rolls operating at different speeds. The bottom feeding roll revolves at 20 rpm and the top discharge roll at 100 rpm. These rolls are water-cooled steel cylinders carefully machined and matched to provide even pressure. The chocolate paste is fed into the bottom pair of rolls. The thin layer of chocolate which forms is carried up through the series by the increasing speed of each roll. When the film of chocolate reaches the top roll it is removed by a scraper blade. As a result of the chilling and grinding, the chocolate becomes a fine powder. The speed of the rolls, and the spacing, are all important in getting a combination grinding and shearing effect.

Pulverizing

Pulverizing is the operation of reducing hard dry particles to powder form by crushing and grinding. An example in the food field is the manufacture of powdered or confectioners' sugar by putting granulated sugar through a hammermill, usually with 3 per cent added cornstarch to prevent caking.

BREAKING

Breaking is the unit operation in which large pieces of material are divided into smaller pieces by the use of sustained pressure or a sharp blow.

Crushing

Crushing is a type of breaking by sustained pressure and is extensively employed in the food industry. Extracting juice from fruit usually involves crushing, followed by pressing. Crushers used for grapes consist of two fluted metal rollers which revolve toward each other. The gap between the rolls is sufficient to crush the grapes but not the seeds. The Garrola crusher mashes the grapes by impact against revolving paddles inside a perforated cylinder.

In the manufacture of olive oil in California, olives are first crushed between revolving steel rolls. Then the pomace from the first pressing is placed in equipment known as an edge roller. This consists of a large shallow bowl in which revolve two heavy wheels. This thoroughly crushes the pulp, liberating the oil.

Canned pineapple juice is a popular item. The juice is liberated either by a device using the screw or worm principle of crushing the fruit, or by a machine using an elliptical drum rotor the surface contour of which develops a kneading action rather than consistent pressure. Carefully controlled runs with the latter indicate a higher yield with less solids in the juice.

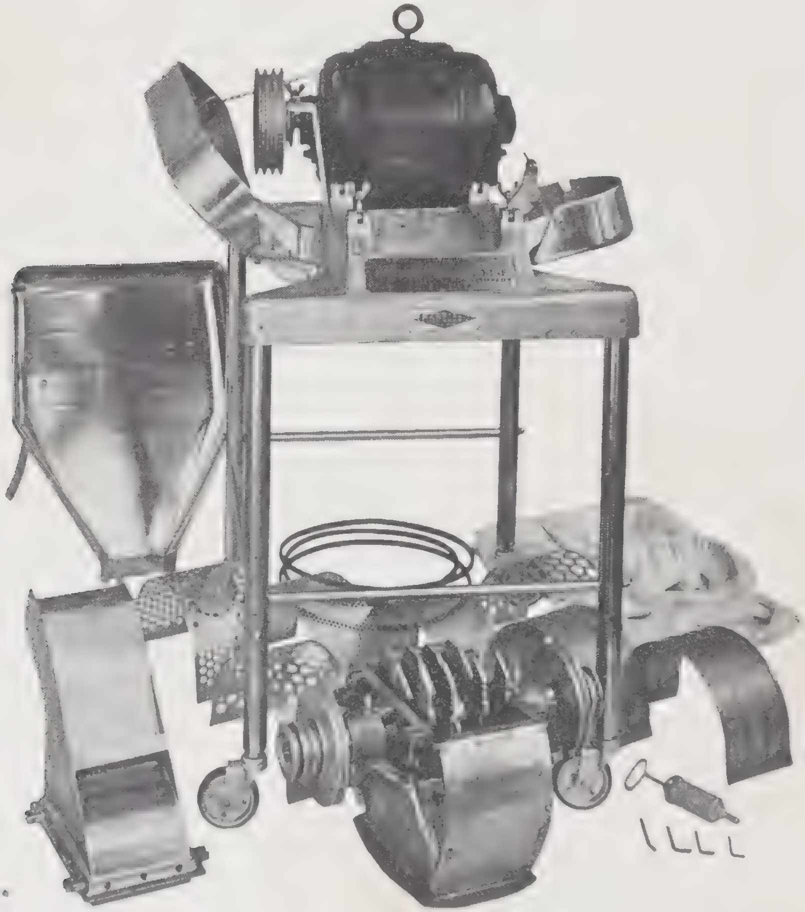
Subjecting tomatoes to high temperatures as soon as crushed greatly improves the flavor of the juice. The tomatoes are fed into the receiving hopper and crushed and then forced in the heating chamber at 150°F.

Large cakes of chocolate may be broken up by a three-roll crusher, the fine material being removed by a bucket elevator.

To release the sugar-bearing juice, sugar cane is milled by crushing and grinding to rupture the plant cells by pressure. Mature cane being very hard and tough, and the amount running to several thousand tons a day, the equipment must be very large and heavy. Large steel rolls, 6 to 7 feet wide and 3 feet in diameter, deeply grooved to prevent slipping, are required.

Pulping

Pulping is a term used to describe the operation of converting foods of definite size and shape into soft formless masses. This is an important operation in several respects. In the canning of fruits only fresh, sound material is used for processing but there is almost always a sizable quantity of edible fruit that is graded out. Aside from the moral obligation of not wasting food, the first grade material would be priced out of the market if it had to bear the loss involved in discarding the seconds. Such so-called waste fruit may be utilized by crushing, packing, and sterilizing for confectioners; by pulp-



Courtesy W. J. Fitzpatrick Co.

FIG. 18.8. Stainless steel comminuting machine with parts disassembled for cleaning showing various types of cylindrical screens used in pulping fruits and vegetables

ing, concentrating, sweetening, and packing for ice cream; by pulping and selling as such; by pulping and converting into jams; or by pulping and using in the manufacture of flavors.

The pulping of fruit for the manufacture of jams is accomplished by a comminuting machine equipped with circular sieves over which brushes revolve and disintegrate the fruit, forcing the pulp through the sieves (see Fig. 18.8).

Certain tomato products are made from pulp, the latter representing edible but otherwise undesirable tomatoes. The sorted and trimmed tomatoes are converted into pulp by use of a pulper or cyclone. This machine is a horizontal metal cylinder in which paddles revolve. The tomatoes are broken by impact, the juice and pulp running through a screen; the skins, seeds, and other extraneous material last out over the lower end of the screen. Instead of using paddles, one type of pulper uses centrifugal force to throw the tomatoes against an upright cylindrical screen.

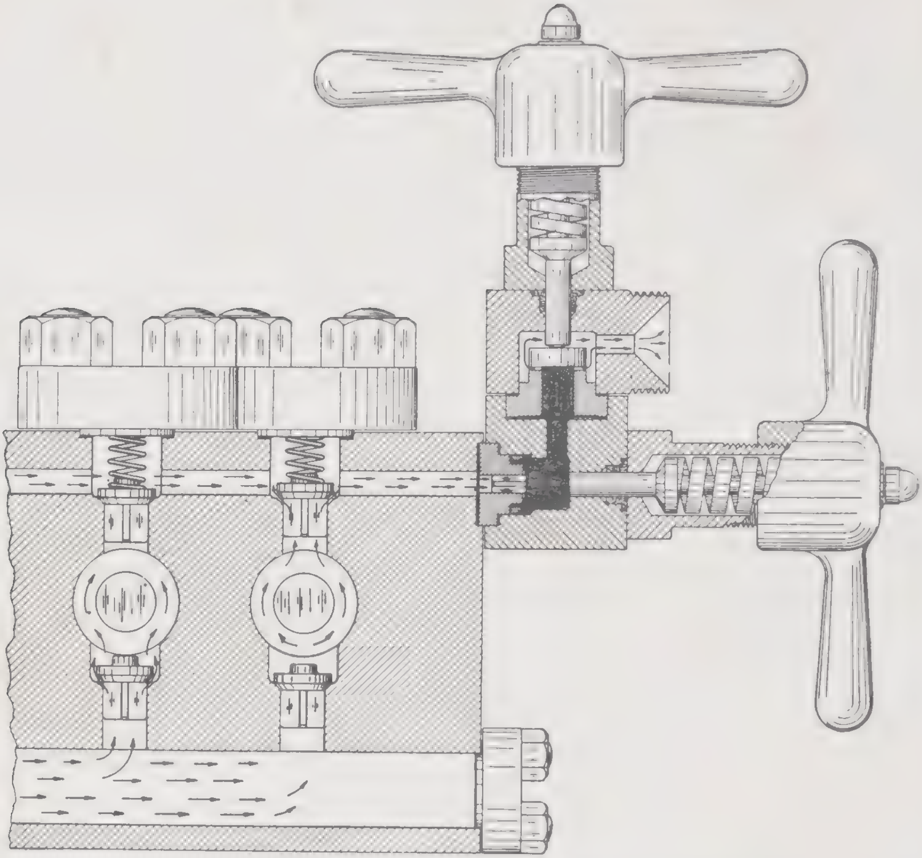
Only recently has a satisfactory bottled or canned citrus juice been possible. The old method of crushing and pressing the whole fruit has been abandoned since it was discovered that the terpenes in the essential oil of the rind change in flavor on storage. Current methods call for cutting the fruit in half and reaming out the juice and pulp on rapidly revolving cones.

HOMOGENIZING

In discussing *homogenizing*, or homogenization as it is commonly referred to, we are confronted with two simultaneous effects. One effect, as the name itself implies, is to produce particles of the same or similar size. The other effect is to produce a relatively permanent mixture. Consequently, homogenizing is both a disintegrating and a mixing unit operation. However, since its mixing character is the result of its disintegrating function, it would appear that the latter has the priority in classification.

Many theories have been advanced concerning the manner in which homogenization is performed. According to the one now accepted, the disrupting, or disintegrating, action takes place as the result of a shearing action between globules or particles of a mixture as they pass through restricted passages at high velocities, much as jagged rocks are sheared and worn into smooth stones, pebbles, and sand by the action of fast-moving water. The solid particles in the shallow or recessed portions of a river, for example, are retarded somewhat by the friction of the fluid on its banks whereas those in the middle or in a rapidly flowing channel of the stream move much more rapidly. These differences in speed cause the solid particles to grind against each other with a shearing effect, with consequent reduction in size as well as the breaking-off of still smaller particles.

The action in a homogenizer produces a greatly magnified shearing effect



Courtesy Manton Gaulin Mfg. Co., Inc.

FIG. 18.9. Cross-sectional drawing showing the flow of fluid through the homogenizer cylinder head and the homogenizing valves.

because of the high velocity of the fluid and the minute orifice through which it is forced. In addition to this shearing effect, there is also a disruptive action due to the impact taking place when the high-velocity streams strike a solid surface such as a breaker ring, for example, used in some types of homogenizing valves. In fact, the various types of valves used in homogenizers seem to confirm this shearing theory (see Fig. 18.9). Some of these valves break up the flow into many small streams by means of numerous small orifices and give turbulence to extremely thin layers by use of the relatively large area flat valves grooved on their face. One very interesting type of valve consists of a small single service cone of stainless steel wire compressed into conical form so that it fits into a conical seat called a retainer. The result of this construction is to break up the flow into a myriad of minute streams and to give the product passing through innumerable shearing treatments. The fact that this valve gives homogenizing results at approximately one-third the pressure of most conventional valves seems to provide additional support to the theory postulated above (Fig. 18.11).

Many foods require homogenization including fruit juices and such dairy products as the type of fluid milk termed "homogenized milk," ice cream mix, cultured sour cream, cultured buttermilk, reconstituted whole milk (made from powdered skim milk and butter). In milk products, homogenization has the effect of breaking up the fat globules into numerous smaller ones, so tiny that they will no longer rise to the stop surface to form a cream layer. It also reduces the curd tension of milk (see Volume I, page 312). In homogenizing fruit juices, the suspended particles are reduced in size so that they no longer sink to the bottom to form a settling layer—the opposite effect of that in milk. The canned frozen egg industry uses this process for the production of a whole egg product which will not separate upon thawing.

Homogenization will often assure uniform and permanent body in many foods as the reduction in size of particles with consequent increase in surface area and uniformity of size tends to stabilize the emulsion. Homogenization, however, should not be confused with emulsification, as the repeated passage of an emulsion through a homogenizer will serve to break the emulsion rather than stabilize it.

There are three general types of homogenizers: valve, single-service cone, and sonic vibrator.

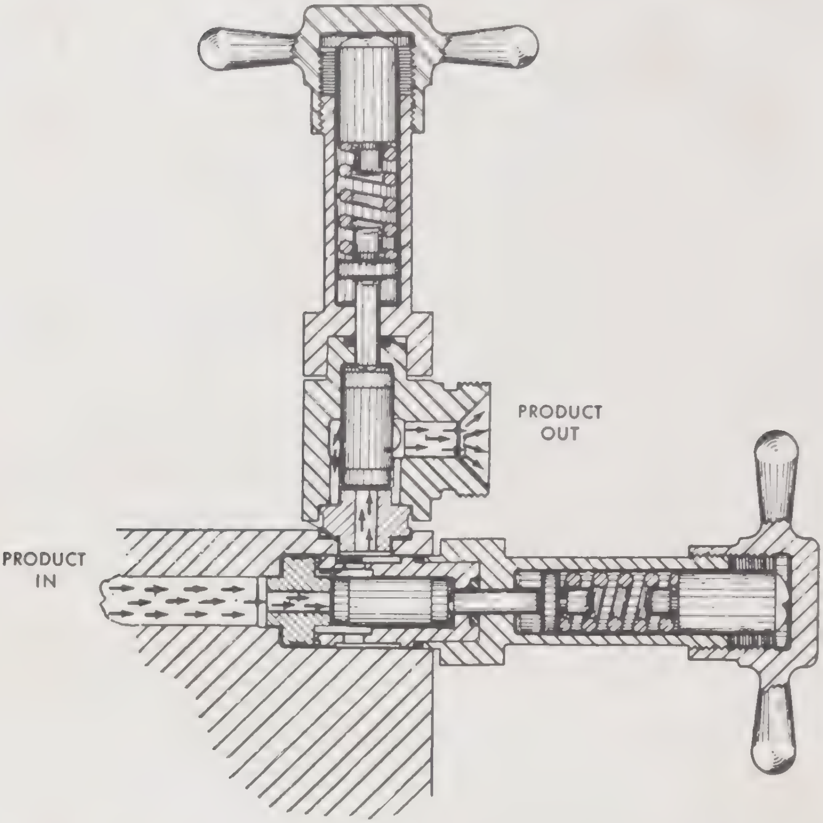
A *valve* homogenizer consists essentially of a valve and high-pressure pump fitted with a minute orifice having an adjustable opening. Fluids are forced through this orifice at high pressure, thereby, causing a marked change in the physical properties of the product treated and producing an intimate mixing of the ingredients of the fluid. Fig. 18.9 shows the elements of a valve-type homogenizer. Fig. 18.10 shows an improved design using perforated stainless steel replaceable valve caps which fit over the mating surfaces of the valve plug and valve seat and are sufficiently machined to provide a multiplicity of shearing ridges.

The *single-service cone* homogenizer has already been discussed as to the functional features of its wire cone. Fig. 18.11 shows diagrammatically the elements of this type of homogenizer.

The *sonic vibrator* homogenizer consists of a flat disc actuated by an electric magnet located over an anvil containing a hole through which the milk passes. The milk passes through the space between the disc and the anvil, the vibrating action of the disc against the thin film of milk hammers the fluid at the rate of 360 cycles per second thereby producing the effects of homogenization.

The following standard for fat separation has been adopted by the U. S. Public Health Service and is widely accepted by the industry in connection with homogenized fluid milk:

> Homogenized milk is milk which has been treated in such manner as to insure break-up of the fat globules to such an extent that after 48 hours quiescent storage no



Courtesy Cherry Burrel Corp.

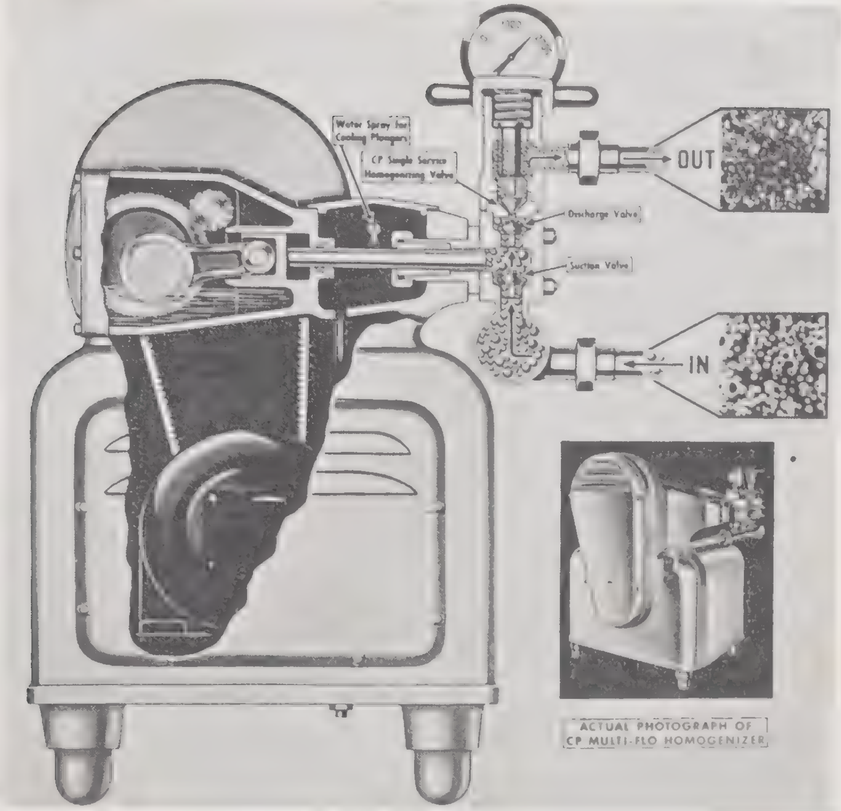
Fig. 18.10. Two-stage homogenizing valve assembly equipped with replaceable valve caps which fit over the mating surfaces of valve plug and seat to improve operating efficiency as well as eliminate necessity of regrinding valve sealing surfaces.

visible cream separation occurs on the milk and the fat percentage of the milk in the top 100 milliliters of milk in a quart bottle, or of proportionate volumes in containers of other sizes, does not differ by more than 10 per cent of itself from the fat percentage of the remaining milk as determined after thorough mixing.

As is the case with sanitary lines and fittings as well as with other sanitary equipment, there are established 3A standards for homogenizers describing material, construction, recording or indicating gauges, gaskets, plunger and valve-rod packing, and sealing methods.

Sanitary principles of design and construction have been developed and applied in colloid mills because liquid and semi-liquid materials are treated in them. This type of mill is used to emulsify perishable food ingredients used in the manufacture of mayonnaise and salad dressings and of fish, nut, and vegetable pastes; it is also used to crush fruit pulp for making fruit juices.

Fig. 18.12 illustrates the various degrees of homogenization obtained with


Water Spray for Cooling Plungers
CP Single Service Homogenizing Valve
OUT
Discharge Valve
Suction Valve
IN
ACTUAL PHOTOGRAPH OF CP MULTI-FLO HOMOGENIZER

Courtesy Creamery Package Mfg. Co.

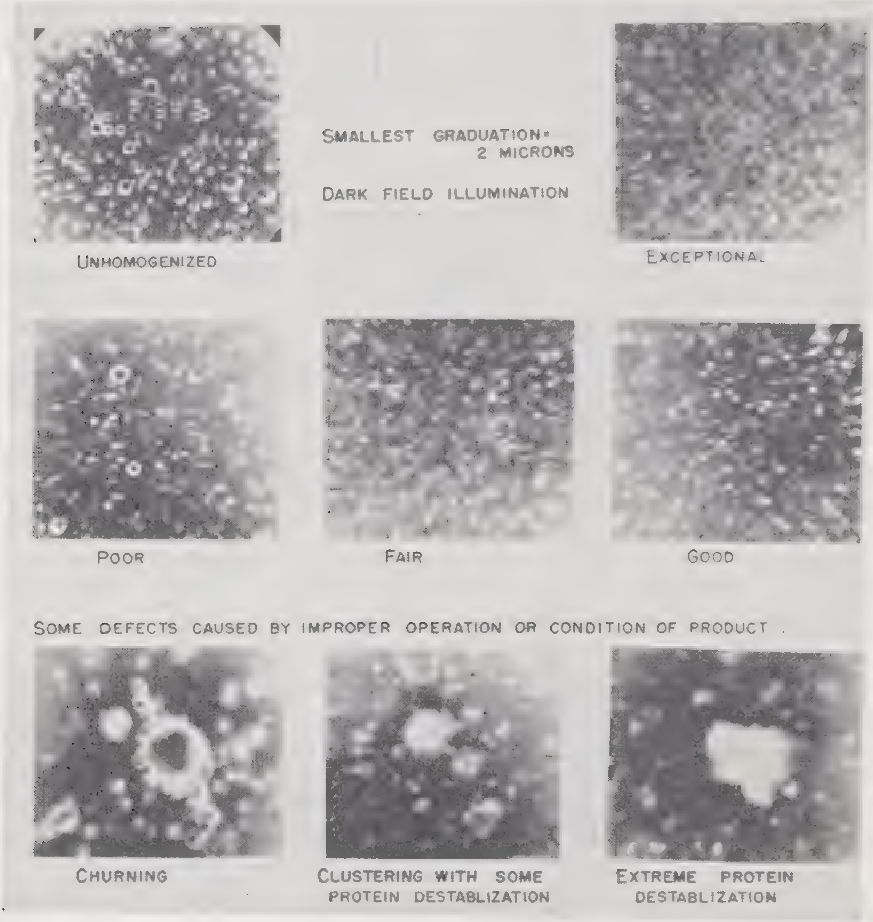
Fig. 18.11. Single-service cone type of homogenizer.

dairy products as well as some of the defects caused by improper operation of a homogenizer or by improper condition of the product itself, or both.

SPRAYING

In the drying of liquid foods, drying is most rapid with minimum impairment of solubility when proper spray drying is practiced. The general principle of the spray dryer is that of a stream of finely atomized particles of fluid being discharged into a stream of hot air. The extremely large amount of surface resented by the droplets causes a practically instantaneous evaporation of moisture, the solids being left in the form of a dry powder which is then separated from the air.

The fluid may be dispersed or sprayed by pressure nozzles or by centrifugal disc or bowl nozzles. In pressure nozzles, the spraying is usually performed by forcing the fluid through a very small orifice at a high velocity. Since most modern spray dryers use the high-pressure atomizer system, a dependable high-pressure pump is essential. The most sensitive as well


SMALLEST GRADUATION= 2 MICRONS
DARK FIELD ILLUMINATION
UNHOMOGENIZED
EXCEPTIONAL
POOR
FAIR
GOOD
SOME DEFECTS CAUSED BY IMPROPER OPERATION OR CONDITION OF PRODUCT .
CHURNING
CLUSTERING WITH SOME PROTEIN DESTABLIZATION
EXTREME PROTEIN DESTABLIZATION

Courtesy Creamery Package Mfg. Co.

FIG. 18.12. Homogenization chart.

as the most important part of the spray dryer is the spray nozzle or atomizer. There are two general types of pressure nozzles, the single fluid type exemplified in a crude form by the ordinary garden hose, and the two-fluid nozzle which is found in insect sprayers or perfume bottles. Most pressure atomizers used in spraying liquid foods such as milk, eggs, etc. are the single-fluid type consisting of two principal parts, the orifice and the so-called "whizzer" or tangent which gives the stream of liquid a rapid rotating motion as it comes from the nozzle, much as the rifling grooves in a pistol spin the bullet.

This whirling action of the nozzle greatly enhances the atomizing effect and results in a finer distribution of the particles. The orifice must be smooth and of the proper shape, for only a scratch may cause streaking in the flow of the product. Pressures up to 5,000 psi are used in operating pressure nozzles, depending upon the volume characteristics of the dryer itself. Maintenance of pressure nozzles is important since erosion will occur with even the hardest material of construction, and once the orifice becomes scratched and non-uniform, good atomization is no longer possible. Therefore, it is necessary to replace pressure nozzles very frequently because of the severe erosion contributed by the solid particles of the liquid foods at the high velocities and pressures used. Drilled jewel discs have been widely used. Even the hardest nozzles have a short operating life, Stellite or Carboloy nozzles giving the longest service. The more perfect the atomization, the finer the dispersion and the more uniform the resulting particle size.

Spray characteristics of pressure nozzles depend on the pressure and nozzle orifice size. The pressure drop affects not only the spray characteristics but the capacity as well. If it is desired to reduce the amount of fluid sprayed by reducing the pressure drop, then the spray may become coarser than desired. To correct this a smaller orifice would be indicated. The use of multiple nozzles tends to overcome this inflexible characteristic of pressure atomization, although several nozzles in a drier can complicate the chamber design and the air flow pattern as well as cause collision of particles, resulting in nonuniformity of spray and particle size. The two-fluid atomizing nozzles are not used in the spray drying of milk and other liquid foods.

In centrifugal disc atomizers, the liquid is extended on discs in thin sheets; the discs rotate rapidly and the liquid is discharged from their periphery into the surrounding hot gases at high speeds. Such rotary atomizers, as they are sometimes called, are used on a few liquid food spray dryers but not nearly as extensively as the pressure nozzle types. Centrifugal atomizers control the degree of atomization largely by their speed which varies from 3,000 to 20,000 rpm. Such atomizers have the advantage of being practically nonclogging and also of requiring no high-pressure pump, while their disadvantages are the limitations on certain shapes of drying chambers and the upkeep of the high-speed bearings.

19. Separating (continued)

As was pointed out in Chapter 15, the unit operation of *separating* has at least twenty-three or twenty-four subdesignations that are commonly used. In Chapter 15, for example, we discussed grading as the important separating unit operation involved in the assembly of raw materials. In Chapter 17, we discussed the operations concerned with sorting and otherwise separating raw food materials of solid form for their subsequent processing. Chapter 18 was concerned with disintegrating unit operations which in some cases might also be considered forms of separating in the sense that the cut, ground, or milled end products had been removed from natural raw materials. It might also be argued that disintegrating operations contribute to the conversion of raw materials rather than to their preparation. It was decided, however, to include them in this section on the preparation of raw food materials, as conversion more properly would appear to be under way when the foods are subjected to the effects of those other unit operations which more directly contribute to their preservation or conservation such as heat exchanging, drying, evaporating, etc. We have also elected to include this chapter in this same section as it is concerned with preparing raw food materials of fluid character by separating them from their solid constituents, or vice versa. Therefore, this chapter will be concerned with filtering, mechanical expression, rendering, and solvent extraction.

FILTERING

Filtering is the unit operation in which a heterogeneous mixture of the serous fluids or juices and solid particles of food materials is separated by a medium which permits the flow of the fluids but retains the solid particles. Consequently, it involves primarily the flow of fluids through porous media.

In all filtering operations, the mixture or slurry flows as a result of some motivating force, i.e., gravity, pressure (or vacuum), or centrifugal. In each case, the filter medium supports the particles as a porous cake. This cake, supported by the filter medium, retains the solid particles separated from the slurry (or mixture), and successive layers are added to it as the filtrate passes through. The various filtering methods employed utilize several procedures for applying the driving force to the fluid; different techniques of cake deposition and removal as well as various means for removal of filtrate from the cake subsequent to its formation. All of these influences have resulted in a great variety of filtering equipment. Generally, filters are classified according to the nature of the driving force initiating the filtration itself.

Gravity Filters

The simplest, and perhaps the oldest, type of filter known to food processors is the jelly bag through which the housewife filters juices prior to making jelly. We find its counterpart in industry in the sanitary milk filter (see Fig. 16.11) or in the conical bags made of canvas, felt, or some heavy fabric used for the preliminary straining of fluids or juices to be clarified later by more effective means. Most juices do not yield a clear filtrate without prior admixture with some suitable filter aid. Olive oils, however, filtered through bag filters yield a clear oil freed of most of the water and solid impurities.

Metal strainers and paper filters are other forms of simple gravity filters. Strainers generally consist of a metal mesh or woven wire basket which retains solids while permitting the fluids to flow freely. They are readily cleaned by inverting and rinsing with a stream of water or compressed air. Pipeline strainers are of similar construction but designed to align and fit in snugly upon assembly and reassembly. They are advantageous to use not only to safeguard pumps from mechanical damage by any foreign metal scraps or stones but to reduce the clogging of ells or valves with splinters, leaves, peelings, and similar solid particles. They also improve quality of product by eliminating foreign materials. When metal mesh strainers are magnetized, even microscopic particles may be removed from liquid foods although they have little, if any, attraction for nonferrous contaminations. Stainless steel filters are available in extremely fine mesh, or porosities of from 20 to 65 microns, for example. These porous filters are available for 1½-inch sanitary tubing and in a variety of shapes and sizes as are the coarser mesh strainers. To obtain a brilliantly clear oil during its final purification, olive oil is filtered through folded filter paper in tin funnels. Pulp filters are sometimes modified to incorporate a porous stone filtering surface.

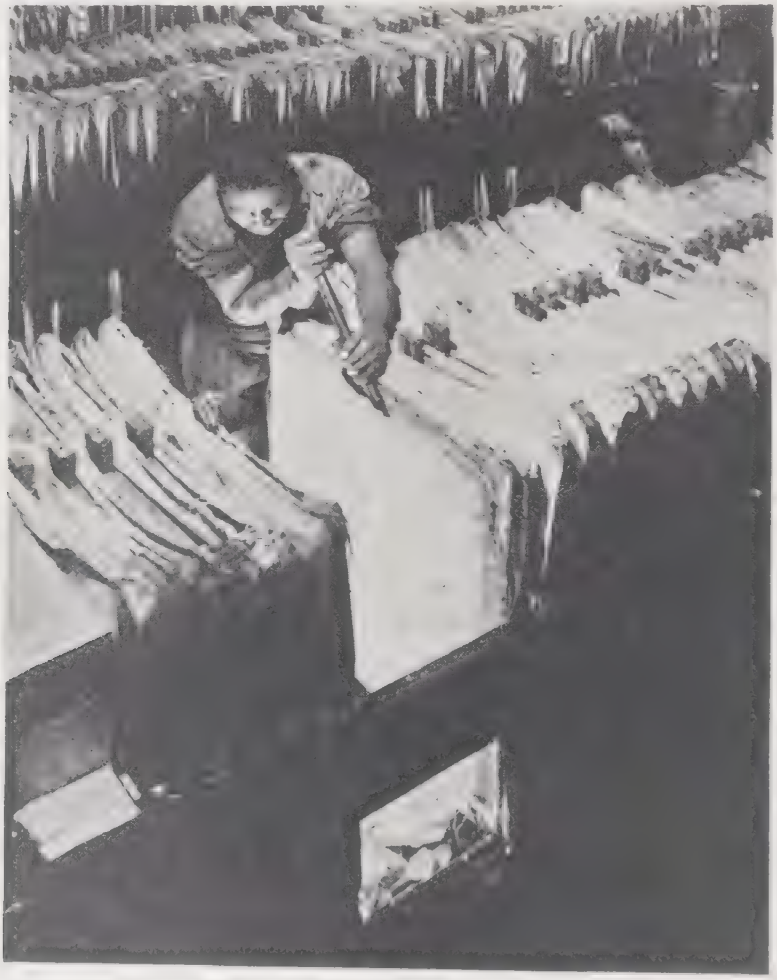
Sand filters have limited application in filtering fluid foods but are used extensively in the filtration of water and wastes. Gravity-operated sand filters consist essentially of tanks with perforated bottoms filled with porous sand through which fluid passes in laminar flow. Tanks may be constructed of wood, steel, or other suitable metal depending upon their uses. However, for water treatment they are usually made of concrete. Ducts beneath a perforated false bottom conduct the filtrate from the bed and are provided with gates or valves to permit backwashing of the sand bed for removing accumulated solids by reversed flow. The perforated bottom is covered with a foot or more of crushed rock or coarse gravel to retain the sand above. The different sizes of rock, gravel, and sand should be carefully and evenly laid in layers so that different sizes of filtering material are not mixed. The sand used for filtering should be uniform in particle size to provide the maximum filtering rate. Pressure-type sand filters are also available but for relatively more limited capacities of water treatment.

Pressure Filters

Filter presses are used extensively in such food industries as those engaged in making yeast, starch, wine, vinegar, extracts, beverages, syrups, and various edible oils. There are many different types of filter presses employing plates and frames. The usual filter press consists of a series of grooved plates and open frames, usually of metal construction, arranged alternately on a press rack and between which are placed filter cloths or canvas mats so that each combination of one frame and one plate surface acts as an independent filtering unit. All the frames are pump-fed from a common supply, with the result that the fluid or juice filters through the cloth into the grooves of the plate. The filtrate leaves the press plate by means of a spigot which serves as a cut-off valve in case a cloth breaks or otherwise fails to filter properly. In such cases, the offending filtering surface is shut off and the filtration continued with the other filtering surfaces until the frames are filled with residue (or cake), at which time the pressure in the system rises rapidly. The liquid to be filtered is usually mixed with a small amount of filter aid, which collects on the cloth surface and decreases the porosity, resulting in more effective removal of the suspended matter. At the conclusion of the operation, air pressure is usually applied to force the remaining liquid from the press, or water is used to wash the filter cake. After the cake is blown down or washed, the flow is stopped. The racked frames and plates are then opened in sequence when the cake is removed and peeled off to fall into a pit or onto a conveyor belt beneath the press to be collected either as the end product or the filtered by-product (see Fig. 19.1). After the plates are cleaned of their cake, and perhaps rinsed off, the press can then be again closed and by mechanical force the frames and plates locked together for a new cycle of filtration to be started.

The common method of operating filter presses is to filter at a constant rate of flow of filtrate during the early part of the cycle. As soon as the cloths are well coated with cake and the filtrate is clear, the pressure is increased to the maximum and the filtration is continued and completed under conditions of constant pressure until the frames fill with cake to the degree where the pressure starts to rise rapidly. If the material to be filtered is stored in tanks, agitators should be provided so that a uniform suspension is fed to the presses as when slurries are being filtered, for example. Reciprocating pumps are not generally adapted to handling slurries and are undesirable as the pulsations tend to make an unduly compact cake. Centrifugal or diaphragm pumps are generally used to supply the motive force for operating the filter presses.

Filter presses use a variety of filtering surfaces such as filter paper, filter cloth, filter bases of glass, wool, asbestos, rubber, woven metals, etc., with or without wire screen supports. Usually some filter aid is used as it forms a nonpacking layer on the filter cloth and prevents sliming or clogging. Juices are filtered before the addition of sugar because the increased vis-



Courtesy Corn Industries Research Foundation

FIG. 19.1. Gluten press. The gluten cake is pried free from the filter press and drops to a conveyor belt below.

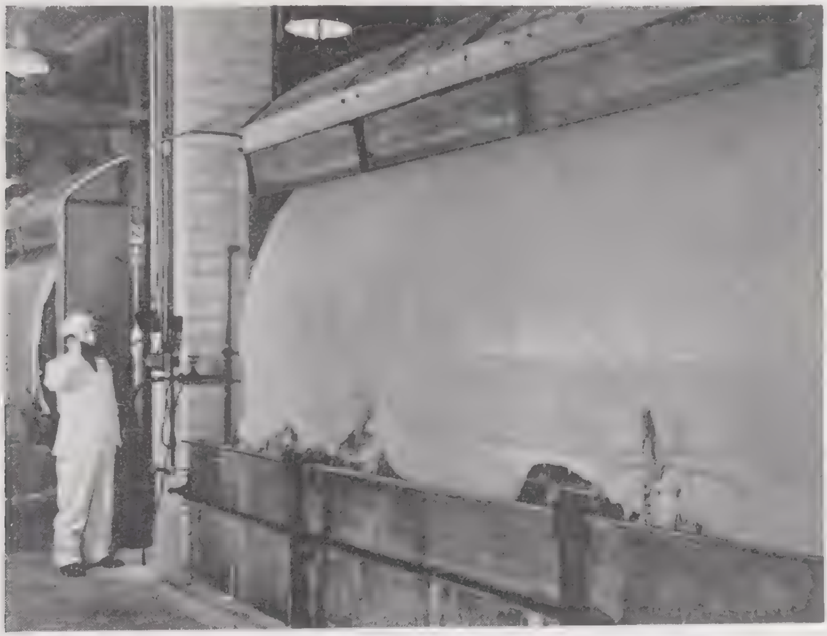
cosity after sugar additions makes filtering too slow or even impossible. Plate and frame filters have the advantages of low cost; use of unskilled workers, inexpensive auxiliary equipment, and easily replaceable parts; long life; almost continuous operation for low solids liquids; and of being ideal for small batch operations. Their disadvantages are the high labor cost of operation, due to manual methods of removing cake, leakage developments, and uneven distribution of cake.

Other types of pressure filters include leaf filters, pulp filters, disc filters, horizontal plate filters, pressure leaf filters, pad filters, and candle filters.

Suction Filters

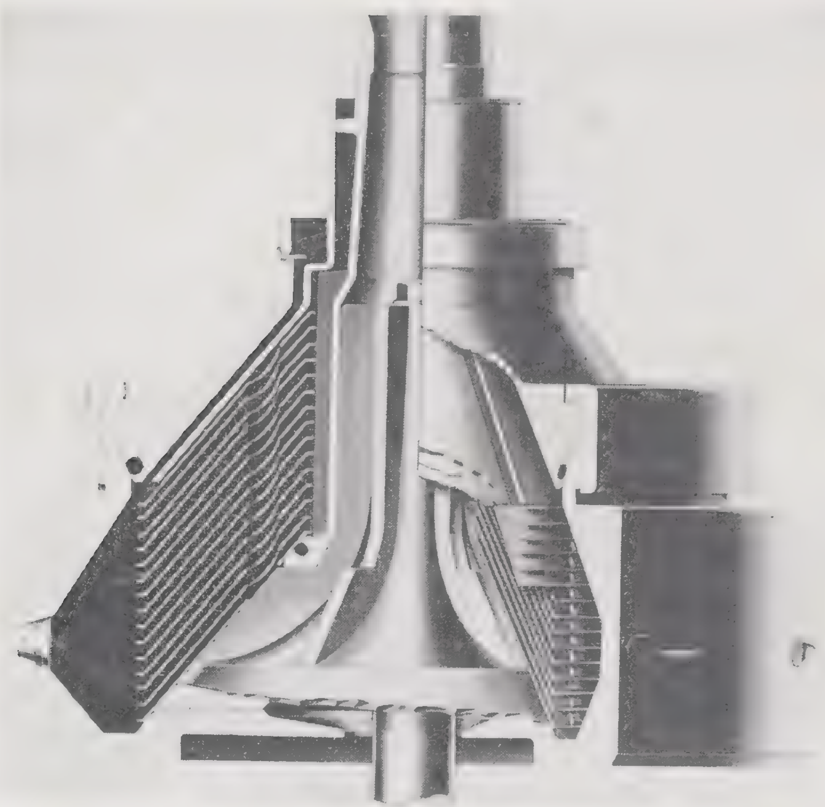
The simplest type of suction filter, well known to every food-engineering student, is the laboratory Gooch or Buchner funnel in which a porous filtering surface is provided either in the form of sintered glass, washed asbestos, or filter paper. In food industries, the counterpart is found in the batch type of suction filter in which a porous plate supports the filtering surface, usually some form of filter cloth. Suction is applied to the receiving tank below the filtering surface and the liquid to be filtered is introduced into the chamber above the filter cloth. The cloth and filter aid remove solids or floc while the clarified liquid passes into the receiving chamber.

Another common type of vacuum filter consists of a rotating drum having a filtering surface along its periphery. This drum rotates on an axis in such



Courtesy Corn Industries Research Foundation.

FIG. 19.2. Rotary starch filters for washing and dewatering starch.



Courtesy DeLaval Separator Co.

Fig. 19.3. Cross section of bowl of centrifugal separator with outlets for two lighter liquids from center and nozzles for discharge of heavier liquids and solid impurities from periphery.

a manner that the drum dips, to varying depths, into a slurry tank. As the drum rotates, suction is applied, usually within shallow compartments fabricated on the surface of the rotating cylinder or drum and automatically operated and controlled. The filtrate is drawn in and directed to a separator and receiver while the cake remains against the drum surface. As the drum rotates further the suction continues and the cake may be washed by a water spray, the wash filtrate being discharged into a separate receiver or run-off system. The drum continues to rotate to a knife that scrapes off the cake and simultaneously the partial vacuum is displaced by a positive air pressure that loosens the cake from the filtering surface (see Fig. 19.2).

Centrifugal filters and desludging separators are used in food industries where the magnification of the force of gravity is essential or desirable. The action of gravity may be enormously increased by the application of centrifugal force depending, of course, upon the peripheral velocity (rpm) of the centrifuge and the diameter of the basket. Some commercial centrifuges may be operated at several thousand times the pull of gravity whereby a settling of solids is effected almost immediately which otherwise might require several days. Some centrifuges are intermittent in operation whereas others are virtually continuous where provisions are made for the discharge of the sludge, or filtrate, without stopping to clean the bowl or basket. Prior filtration generally improves results obtainable with centrifugal filtration by reducing the rate of solids build-up in the centrifuge bowl or basket (see Fig. 19.3).

EXPRESSING

Oil-bearing seeds contain higher percentages of solids in proportion to the oil present than do animal tissues. This makes the extraction of oil more difficult and necessitates adequate pretreatment. The very important matter of pretreatment varies as to detail, depending upon the seed under consideration, but the general principles involved may be illustrated by cottonseed.

Cottonseed as it comes from the gins passes through delinters to remove the remaining adhering short fibers. The delinted seeds next pass through decorticators which split the hulls by means of revolving knives. The hulls are separated from the kernels by means of vibrating screens and aspirators. The kernels are flaked by passing them under smooth steel rolls. This flattens and compacts the kernels but the pressure is insufficient to express the oil.

The flaked kernels, or meats, pass to a line steam cooker operating at about 230°F for 1½ hours, or to 260°F for 15 to 20 minutes.

Hydraulic Pressing

This type of mechanical expression uses oil or water and a pump to produce the desired pressure. The liquid is pumped into a heavy cylinder attached to the press. The ultimate pressure to be obtained is in the ratio of the diameter of the pressure cylinder piston to that of the pump. For heavy pressures the diameter of the pump must be small and that of the cylinder large.

The extraction of cottonseed oil from the cooked meats described above is accomplished by wrapping them in cloth made of hair and subjecting to pressures of 2,000 pounds per square inch. The resulting cake contains 32 per cent protein and 4 to 6 per cent fat and finds extensive use as an animal feed.

Miscellaneous Pressing Techniques

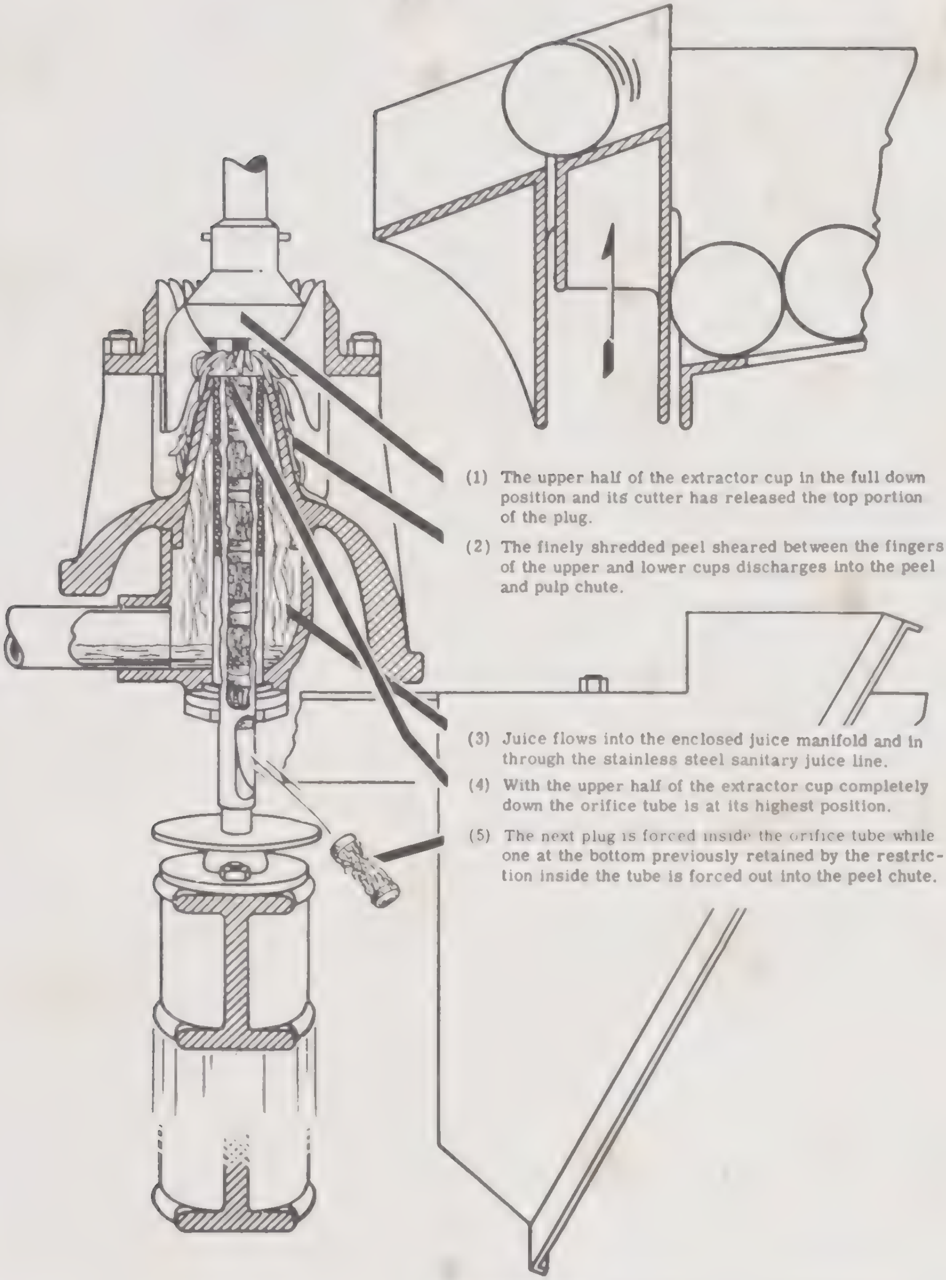
In designing citrus juice extractors, the necessity for eliminating or reducing the essential oils from the peel has been taken into consideration. In addition, any press should keep the juice from contact with air as much as possible. In the home juicer, the fruit is commonly cut in half and the juicy pulp reamed out of the peel. This principle has been applied commercially. A rotary-type extractor cuts the fruit in half while held by cups in two horizontal rotating cylinders. As these cylinders turn, a series of protruding knives push into the halved fruits to press out the juice.

Juice from various citrus fruits may now be extracted in such a way as to preserve the original delicate flavor and in a highly sanitary manner.

A cam-actuated fruit elevator feeds one fruit at a time into each extractor cup, the fruit automatically positioning itself. An intermeshing multifingered upper extractor cup closes down on the fruit in the lower cup with controlled pressure. Circular cutters in both cups punch a small hole in the top and bottom of the fruit. Juice and seeds are forced down through the lower cutter into the prefinisher tube. The juice flows through the perforated walls of the prefinisher tube into an enclosed juice manifold. The orifice tube rises to press additional juice from the juice cells inside the prefinisher tube. The peel is then disintegrated by being forced through the fingers of the two cups, and discharged into the waste conveyor (see Fig. 19.4).

The drum-type pineapple juice extractor employs an elliptical drum rotor for kneading the crushed pineapple instead of using the conventional screw which exerts constant pressure. This method gives higher yields of juice than the screw press although with a lower total solids content.

The screw type juice extractor consists of a large, smoothly polished screw rotating in heavy duty bearings. The bottom of the screw flights are tapered, the deepest flights being at the feed end, with shallow flights at the discharge end. Coarse and fine screens are available for separating the pulp from the juice. The machine is used for making tomato juice from cold or scalded whole tomatoes, or from tomatoes which have been chopped or heated. Screw-type juice extractors when operated at about 400 rpm will handle about 400 to 500 bushels of tomatoes per hour, with an output of 30 to 40 gallons of juice per minute. Crushed, preheated tomatoes give the highest capacity. The *density* of the juice may be varied from a thin watery *consistency* to a heavy pulpy juice by adjustment of the hand wheel at the discharge end of the machine.



(1) The upper half of the extractor cup in the full down position and its cutter has released the top portion of the plug.

(2) The finely shredded peel sheared between the fingers of the upper and lower cups discharges into the peel and pulp chute.

(3) Juice flows into the enclosed juice manifold and in through the stainless steel sanitary juice line.

(4) With the upper half of the extractor cup completely down the orifice tube is at its highest position.

(5) The next plug is forced inside the orifice tube while one at the bottom previously retained by the restriction inside the tube is forced out into the peel chute.

Courtesy Food Machinery & Chemical Corp.

Fig. 19.4. Diagrammatic sketch of citrus juice extractor.

When used for handling citrus juices, this equipment is usually employed as a finisher. A very satisfactory separation of juice and pulp may be made.

The extraction of oil from the skins of citrus fruit is an important operation. The peels are cut and pressed in stainless steel equipment, the oil passing through a perforated screen into a tank. From the latter the oil is pumped to a centrifuge for further separation and clarification. As much as 3,000 pounds of orange peel per hour can be handled by one unit. Output of lemon peel is about one-half as much. The recovery of essential oil from oranges averages $3\frac{1}{2}$ to 4 pounds per ton of orange fruit.

Another method of extracting citrus oil consists of removing the rind, dipping it in water, and pressing by hand with a sponge. The oil absorbed by the sponge is then squeezed to press out the oil as described in Volume I.

A third method consists of puncturing the oil cells in the rind by rolling in a bowl containing sharp points. This releases the oil which is collected in the bowl.

The sack and cloth press, commonly used for making apple juice, is satisfactory for general pressing applications. The crushed fruit is placed on heavy cotton cloths of coarse weave to a depth of three inches. The edges of the cloth are folded over toward the center. A wooden rack of heavy hardwood slats is placed on the folded cloth and a second cloth containing crushed fruit is placed on top. When the press is filled, pressure is applied. The juice runs down over the racks into a reservoir below.

The basket press is used for pressing grapes for wine. Pressed fresh grapes make white wine. Fermented grapes are used for making red dry wine. This equipment consists of a slatted cylinder of wood, heavily reinforced, standing in a round shallow tub of wood. The "basket" is filled with fruit, and the whole unit pushed under a hydraulic press. The juice is extracted by pressure and runs between the slats into the tub.

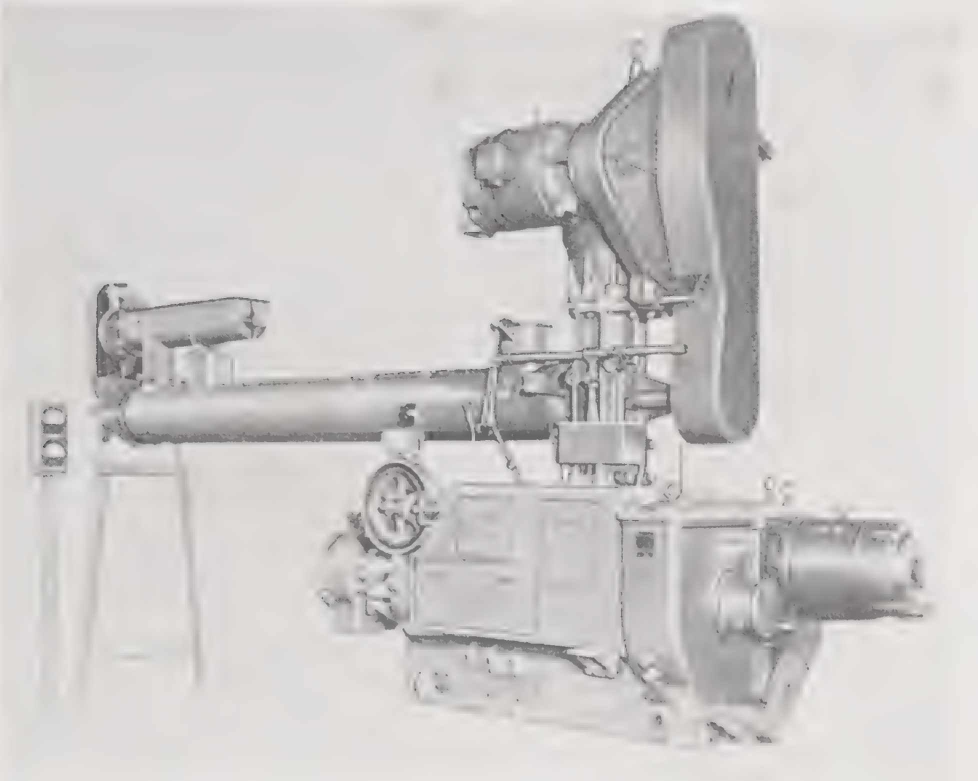
The beam press *refers merely to the method* of applying pressure. Downward pressure is exerted by means of a long wooden beam. The longer the beam, the heavier the weight, and the further from the fulcrum it is applied, the greater the pressure.

The conventional horizontal frame and plate filter press is used. This equipment has been described earlier in this chapter.

Continuous presses have been developed. The fruit is fed into one end, whole or crushed, and pressure applied. The juice escapes through openings in the bottom of the press while the pomace is discharged continuously at the other end. The press consists of a cylinder with a perforated bottom, hopper, adjustable exit opening, and a conical screw which rotates within the cylinder. The fruit enters the hopper at the large end of the unit and is forced through the cone toward the smaller end.

Expelling

Anderson was the first to apply the principle of the screw press to the extraction of oils. Registration of the name Expeller to cover the first machine patented in 1900 has made the name common to everyone in the oil milling industry (see Fig. 19.5).



Courtesy V. D. Anderson Co.

FIG. 19.5. Twin motor Super Duo Expeller.

Except for the cooking operation, pretreatment of the meats is the same as that described above. Meats intended for the expelling operation are put through a continuous cooker-conditioner at 240° F which reduces the moisture content to 2.5 to 3.5 per cent. The screw operates in a slotted housing against a restricted opening. Pressures of 15 to 20 tons per square inch are developed. The oil runs through the slots. The resulting cake contains 4 to 5 per cent residual oil and is sold as animal feed. The Expeller is a labor saver and is ideally suited for use in oil mills of limited capacity. Various sized units are available, ranging from 3 to 7 tons of raw material per twenty-four hours up to 200 tons per day.

RENDERING

Rendering is the term used to describe the operation of extracting oils and fats from animal tissues. Heat makes the cell walls more permeable to the water and fat in the tissues, hence the application of heat is a necessity regardless of the method of rendering employed. Actually, rendering is heat extraction.

The fatty tissues are chopped into small pieces and rendered promptly in order to avoid enzymatic action. The lipases produce an off-flavored fat owing to the production of free fatty acids. When the rendering is done in the presence of added water, it is termed wet rendering. If no water is added, and the water naturally present in the tissues is partially evaporated during the operation, it is called dry rendering. The water present in either case is important since it serves to coagulate the protein of the cell wall to increase permeability.

Wet rendering may be done at low temperatures to get a bland fat. The chopped tissues are placed in open steam jacketed kettles equipped with agitators. Water is added and the mixture heated while being stirred. The fat rises to the surface and is skimmed off. The residues are reprocessed to increase the yield and finally put through an expeller or screw press. Since the yields are not satisfactory in the low temperature method, the packer prefers to extract under 40 to 60 pounds steam pressure, then deodorize to secure blandness. The apparatus is an autoclave in which the fat is rendered under pressure over a period of four to six hours.

Dry rendering is accomplished in open steam jacketed kettles with agitators. The temperature is raised to 220 to 230°F. The coagulated tissues, known as "cracklings," settle to the bottom. The darker colored and characteristically flavored fat is drawn off the top. This process is made more efficient by closing the kettles and drawing a vacuum to remove the water.

For a more detailed discussion of rendering methods see pages 195–200, Volume I.

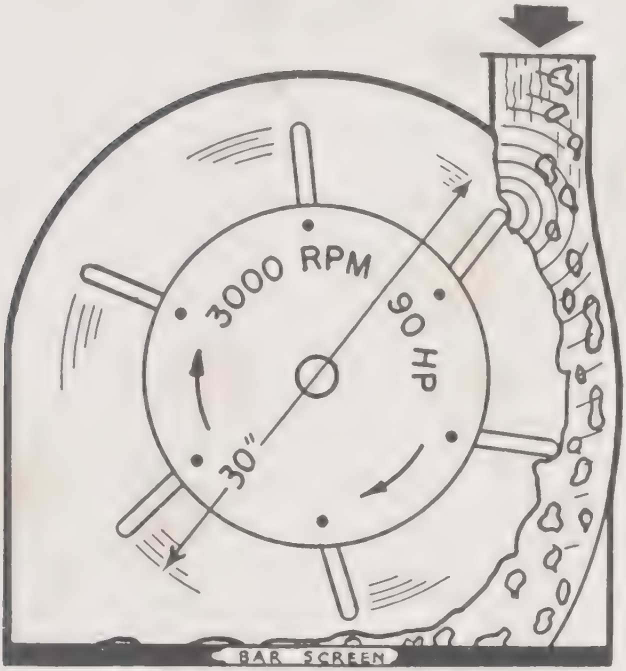
EXTRACTING

Impulse Extracting

This is a recent development wherein the operation mechanically removes oils and fats from vegetable and animal sources without the application of heat. The equipment is a modified hammermill so operated as to mechanically generate shock waves in a falling stream of water. These waves rupture the cells walls containing the oil or fat. Since water replaces the released fat, satisfactory yields of a high-grade product are obtained.

The course of the water stream containing the material to be degreased is shown in Fig. 19.6. The water stream passes through the extractor in less than a second. Each of the six sets of hammers is made up of bars having a cross section of ¾ inch × ¾ inch and rounded, blunt tips. Any grinding action by the hammers, such as found in a hammermill, is entirely incidental to the main objective of having the tips strike the surface of the water stream with tremendous impact. To generate the shock waves in the bone rendering machine used commercially requires 90 hp.

Extraction of vegetable seeds is still in the experimental stage. Fish oils extracted by this method are odorless and the vitamin content substantially higher than normal.



Courtesy "Food Processing"

FIG. 19.6. Impulse extraction mill.

Solvent Extracting

The use of a solvent for the extraction of oleaginous material is recommended when the original oil content is low and when greater yields are imperative. Under the best conditions, mechanical methods never reduce the residual oil in the cake below about 4 per cent. For the extraction of soybeans, the solvent method has much to offer. It is much less popular with the cottonseed processor because the flakes tend to disintegrate in the solvent. The resulting "fines" present numerous operating problems. In such a situation, mechanical pressing of the seeds, followed by solvent extraction of the cake, is worthy of consideration, provided the extra yield of oil justifies the extra cost of handling.

Since the capital investment in a solvent plant is appreciable, it can be justified only when the output is large. One group of construction engineers has developed a prefabricated outdoor solvent extraction system requiring no housing. This lowers the initial investment, fire hazard, and operating expense. The hydrocarbons used as solvents are flammable, and while chlorinated hydrocarbons are excellent solvents and are nonflammable, their higher price restricts their use.

The serious student of solvent extraction must be aware of the rather extensive patent art. The U. S. Patent Office Gazette should be consulted before any research or development is undertaken.

Solvent extraction methods seldom lower the residual oil in the cake below 1.5 per cent. In a recent patented process, known as Exsolex, the residual oil is less than 0.5 per cent. The process essentially is an integral operation that combines expelling with solvent extraction in a unique manner whereby it is applicable to both low oil-bearing soybeans and any high oil-bearing seed.

The Kennedy oil extractor consists of a battery of round bottom tanks in a vapor-tight housing. Each tank is equipped with a perforated paddle which revolves slowly and lifts the flakes out of the solvent in one tank and discharges them into the next. To increase the efficiency, the solvent flows countercurrent to the flakes.

The Bollman extractor is an endless bucket elevator in a vapor-tight housing. The buckets are perforated. The descending buckets are filled when at the top of the unit with flaked meats and sprayed with half-miscella. This percolates through the flakes as the buckets descend. The full miscella is collected at the bottom and discharged into the solvent recovery system. The ascending buckets are sprayed at the top with fresh solvent, which percolates down through the buckets, collecting at the bottom as half-miscella. This is used as indicated above. The extracted flakes are dumped automatically when the buckets reach the top and are carried away by new conveyors.

Cacao butter may be extrated from cacao beans by means of hydraulic pressure, expelling, or solvents. The first two operations are not substantially different from those already described. Solvent extraction of cacao butter does provide enough variation to justify a brief description. The fatty material is placed in a series of extraction tanks equipped with reflux condensers. The fat is extracted on the countercurrent principle. Fresh solvent flows into the tank containing the most nearly exhausted raw material, then progressively passes through the series of tanks until it is finally withdrawn from the tank containing the fresh charge. Heat can be applied to the tanks to facilitate solution. The fat-saturated solvent is then distilled through a fractionating column. To minimize loss of solvent, air and gases escaping from the condensers are scrubbed through oil washers or passed over such absorbents as silica gel or charcoal.

The Bonotto seed-oil extractor is a vertical cylinder fitted with equally spaced disks which rotate on a common shaft. The disks are slotted and a stationary scraper sweeps the seed through the slots to the disk below. Solvent is introduced at the bottom of the cylinder and the miscella is removed through a screen at the top. The extracted flakes are removed from the bottom by means of a screw which pushes the flakes through an orifice at the bottom. This compresses the flakes into a plug which will not permit the solvent to pass and simultaneously presses the solvent from the discharged flakes.

Essential oils are important members of the food flavoring group. One method of separating them from the plant tissues in which they occur is by distillation. This unit operation will be described later. Mechanical pressing of citrus rinds of a given acidity to secure the corresponding essential oil has been discussed. The remaining important method is by solvent extraction.

Four variations of the solvent extraction technique merit consideration.

Percolation. Low-boiling solvents are used to extract the essential oil by passing the solvent through a column of ground raw material at a predetermined rate. The essential oil is recovered by distilling off the solvent.

Maceration. This is the operation of separating an essential oil from the plant tissue by solution, after a period of soaking. One method is to soak the ground material in warm or hot oil, such as odorless and tasteless lard or vegetable oil. The essential oil is recovered from the fixed oil by extracting it with alcohol. The alcohol is then removed by distillation.

Countercurrent Extraction. To secure a terpeneless oil, an essential oil is obtained as enumerated above. This oil is then dissolved in a nonpolar alcohol-immiscible solvent, such as an aliphatic hydrocarbon. A countercurrent stream of this material is directed against a polar solvent, such as alcohol. The hydrocarbon retains the terpenes while the alcohol dissolves the desirable flavoring constituents. Recovery is by distillation.

Selective Solvent Extraction. This is somewhat similar to the above in principle. The essential oil is removed by shaking with a water-alcohol mixture of such composition that the greatest amount of terpene-free oil is extracted.

20. Pumping

In our discussion of the materials handling of liquid foods in Chapter 14, we confined the subject matter to the conveying means employed, including pipes and fittings. It was stated therein that "as pumping is essentially of fluid or gaseous materials handled by hydraulic or pressure means, in contrast to the handling of solid materials by gravity, either in their natural state or in containers having solid characteristics, it was considered feasible to separate them into two distinct unit operations." Obviously most liquids and some gases can be handled by utilizing the force of gravity, although it is equally apparent that in so doing pipes and fittings are necessary mechanical conveyances.

It is, of course, purely an academic convenience to include a discussion of pipes and fittings in a chapter devoted to the materials handling of all foods—solid, semisolid and fluid—thus separating it from the chapter on pumping. This has been done in the desire to impress both the student and the industrial reader with the indispensability of both these unit operations in the commercial performances of practically every food-processing plant. A chapter on pumping could just as logically be placed in Section 1 of this book, as was the chapter on materials handling, for instance. But it seemed that both the unit operations of *materials handling* and *pumping* would be better emphasized if each were accorded separate treatment, even if, in so doing, some continuity in the presentation of subject matter was sacrificed. In any modern food-processing plant intelligent application of effective materials handling systems is essential; so also is intelligent application of efficient pumping systems.

Pumping, for example, is indispensable to practically all food-processing industries, in which the transfer of liquids and gases is a constant need. This involves many pumping problems, since gravity cannot be utilized exclusively. Pipelines and pumps save much labor, and the proper solution of pumping problems is necessary for plant operating efficiency. However, before proceeding with a discussion of hydraulics and pumping, we wish to emphasize with equal force that the contaminating factors that can be introduced by improper sanitary design of piping, fittings and equipment also apply to pumps themselves. Furthermore, the contaminating factors introduced by metals and alloys cannot be ignored in the construction of pumps, any more than in the construction of piping, fittings and equipment. In fact, because of the possibility of greater frictional forces in pumps, it is even more important that due consideration be given to the possible induced erosion of metal parts, which may increase metallic contaminations.

Liquids are conveyed through piping and fittings by other means than the force of gravity and pumping. *Gravity flow* is obviously confined to systems that operate from a higher to a lower level. *Siphon conveying*, however, is accomplished almost as easily and with the same economy as gravity flow, but is also confined to systems operating from a higher to a lower level. Siphons are especially adapted to decantation operations in which a swivel pipe is usually installed in the bottom of a tank and fitted with some arrangement for adjusting the inlet pipe to the discharge level. Automatic siphons constructed with both the inlet end and outlet ends enclosed in a small boot, so that the liquid column will not be broken when the level of the siphoned liquid reaches the siphon inlet, are used occasionally.

Liquids are sometimes lifted or elevated by water, air or steam siphons, or *ejectors*, which operate on the principle of a difference in velocity of steam, for example, issuing from a restricted opening and that of the surrounding liquid. Obviously, liquids so conveyed are subject to aerating or diluting effects, and even heating effects. *Air lifts* are the simplest form of displacement conveying; essentially they rely on air pressures to force liquids into delivery areas. Gases other than air may be used, of course. Air lifts are especially adapted for transporting corrosive, sticky or gritty liquids and suspensions.

Machines that do work on a flowing fluid are called pumps, blowers, compressors, etc., whereas those that remove work from a flowing fluid are known as engines, turbines, wheels, windmills, etc. The effect of most pumping devices is to increase the pressure of a fluid, but some deliver the fluid with an increase in kinetic energy or in elevation. The majority of pumps may be classified as reciprocating, rotary, or centrifugal. Reciprocating and rotary pumps do not permit free flow of fluid through the pump except for leakage past close-fitting parts. They are often referred to as "positive-displacement" pumps.

Before proceeding with a discussion of pumping problems as well as representative types of pumps, we should perhaps discuss some of the more general terms used in connection therewith. All pumps are rated in terms of four characteristics:

1. *Capacity*, the quantity of liquid discharged per unit of time.
2. *Increase in pressure*, frequently referred to as *head*, is the energy sup-

plied to the fluid per unit weight and is obtained by dividing the increase in pressure by the weight of the fluid.

3. *Power*, the energy consumed by the machine per unit of time.
4. *Efficiency*, the energy supplied to the fluid divided by the energy supplied to the machine.

The term *head*, defined above as *increase in pressure*, has several meanings. If the pressure of a fluid is changed to its equivalent height in feet of water, there results what is called *pressure head*. A pressure in pounds per square inch (psi) when multiplied by 2.31 (which is the feet of water equivalent to 1 psi) gives the amount of pressure head. The vertical distance a fluid is above a reference level is called its *static head*. A fluid flowing at some velocity has energy due to this velocity equivalent to its *velocity head*, given by the formula $V.H. = V^2/64.4$, where V is the velocity in feet per second and V.H. is velocity head in feet.

Much of the pumping performed in food-processing plants is of the general-purpose type, such as that for water, air, or refrigerants such as brine, ammonia or "Freon." The handling of liquid and semisolid foods usually calls for pumps of special design, first, to make them sanitary so they can be readily cleaned, and second, to minimizing foaming or churning tendencies. There is also a third type of pumping used in high-pressure work such as is found in the use of the homogenizer, which operates at pressures of 1,000 to 3,000 psi.

POSITIVE DISPLACEMENT PUMPS

Reciprocating Pumps

Reciprocating pumps are of the positive-displacement type. They develop a higher pressure by the direct action of a piston or plunger on the fluid confined in a cylinder, forcing the high-pressure fluid through the discharge valves. Such pumps eject a practically constant amount of fluid, irrespective of pressure, and will build up a bursting pressure or stall the motor in case the discharge line is closed. The piston or plunger may be actuated by a steam driven-piston or a motor drive through a crank and connecting rod (see Fig. 20.1).

The advantages of this type of pump are that it will deliver a constant volume of fluid against a wide range of pressures, especially if power-driven, and can be built to operate against high pressures without serious loss of capacity. It is self-priming for service on liquids, and has practically no leakage or slippage. It generally has long life, is slow in speed, and has wearing parts that are readily replaced.

The valves of most reciprocating pumps prevent satisfactory operation on viscous liquids, and the close clearances cause maintenance problems,

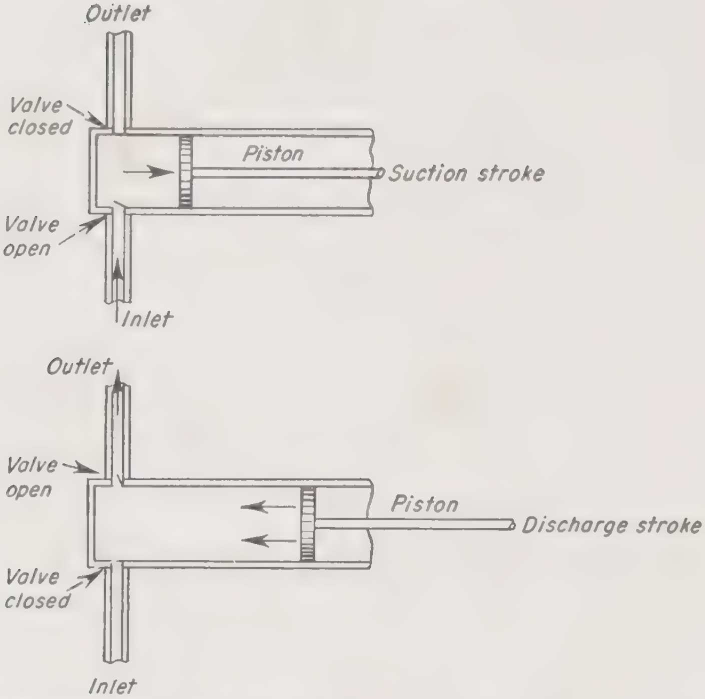


FIG. 20.1. The valve and piston action of a piston-type pump on both the suction and discharge strokes.

especially when pumping fluids or semisolids containing suspended solids. A relief valve and by-pass lines should be provided to prevent damage to the pump or motor caused by any inadvertent closing of the shut-off valve in the discharge line. Maintenance problems and the time needed for valve action in such pumps limit their speed of operation. Besides the fact that they give a pulsating pressure and have valves to keep in repair, reciprocating pumps also have stuffing boxes to contend with, which sometimes present serious contaminating problems with certain food materials.

The efficiency of reciprocating pumps is properly the work done on the fluid divided by the work done on the pump. For a pump driven by an electric motor, this definition of efficiency is generally applied to the combined motor and pump, treated as a single unit, in which case the over-all efficiency is the work done on the fluid divided by the electrical energy supplied to the motor.

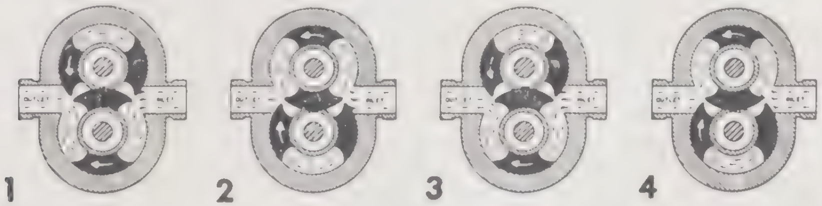
Actually, pump designs are almost as numerous as there are applications in food-processing industries. Generally, they are used to elevate or transport liquids. While all the pumps used in working on fluid foods are not positive-displacement, this type does constitute a considerable proportion of the pumps used. However, the matter of suction in positive-displacement pumps is often neglected, if not ignored altogether. Thus, it should be emphasized that successful operation depends upon the proper proportioning of the suction line. When these lines are too small in diameter or too long, voids develop, with a resulting loss of capacity, and pumping can become a noisy operation. Therefore, for best performance, a consideration of the following is important: (a) vertical distance from the source of supply; (b) entrance losses; (c) velocity losses; (d) frictional losses; (e) absolute pressure required to prevent vaporization of liquid in the suction line; (f) volatility (g) viscosity of the material to be moved; and (h) entrained gases. The effect of the viscosity on the size, length and capacity of the suction line is a most important consideration. The net positive suction head (NPSH) may be calculated from the following formula:

$$\text{NPSH} = \pm Z + \frac{2.31(p - p_2)}{\text{Sp. gr.}} - (H_f + H_e)$$

where Z is static head in feet; p is pressure on surface of liquid; p_2 is vapor pressure at pumping temperature; H_f is friction loss in feet; and H_e is entrance loss from tank to pipe. For boiling liquids, $p = p_2$, and this quantity is omitted from the equation. Slippage in the pump is independent of the pump speed, provided the pressure is constant. The volumetric efficiency is also important and is affected by slippage, entrained gases, and contained volatiles.

Rotary Pumps

Rotary pumps, also of the positive-displacement type, have the same general characteristics as the piston-type or reciprocating pumps, except that they give a more uniform flow. They depend upon close mechanical fits for their efficiency. The rotating parts move in relation to the casing so as to create a space; this first enlarges, drawing in the fluid in the suction line, is sealed, and then reduces in volume, forcing the fluid through the discharge port at the necessary high pressure. Valves are not used in rotary pumps, but small clearances must be maintained for efficient operation.



Courtesy Waukesha Foundry Co.

FIG. 20.2. The rotary-type pump illustrated above shows each quarter revolution of the balanced twin blade impellers. Consequently, the four chambers in the pump-head draw four full product-loads and discharge the same number with each completed revolution of the impellers. This positive displacement pump gives a smooth, virtually nonpulsating, positive flow.

Rotary pumps may be divided into five main types according to the character of the rotating parts such as gear, lobe, screw, vane or cam, although considerable overlapping occurs in specific designs. These pumps are perfectly adapted to direct connection with the motor. They are usually small and balanced well enough not to need a flywheel. The capacity is almost constant within the limits of speed of the driving mechanism for all discharge pressures up to that which will destroy the pump or stop the motor. They are capable of operating with low absolute suction pressure, and require no priming. The discharge ranges from lightly pulsating in some cam pumps to quite steady in gear and vane pumps containing no valves. All rotary pumps are well suited to pumping liquids of relatively high viscosity.

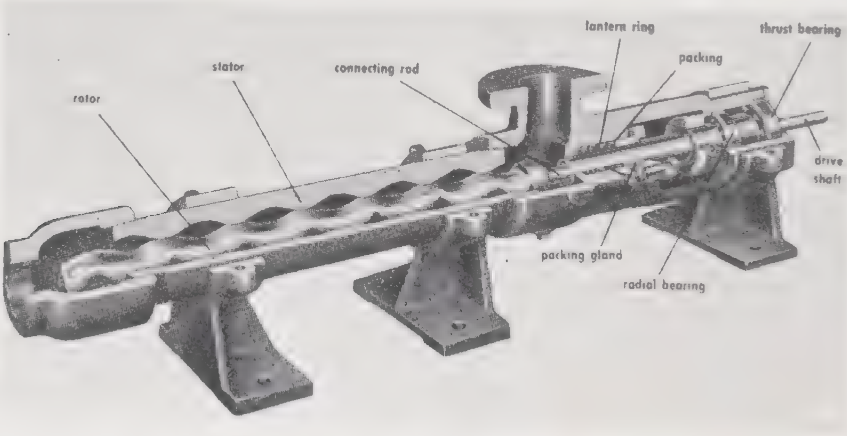
The extremely close clearances necessary in all rotary machines call for precise machining, and thus increase cost as well as maintenance problems. These small clearances and frequent rubbing of the moving parts preclude pumping fluids with no lubricating properties or those containing solids in suspension. The small size, the high discharge pressures and the simplicity of construction of these pumps give them a wide range of application.

A rotary type pump is illustrated in Fig. 20.2.

Variable Flow Pumps

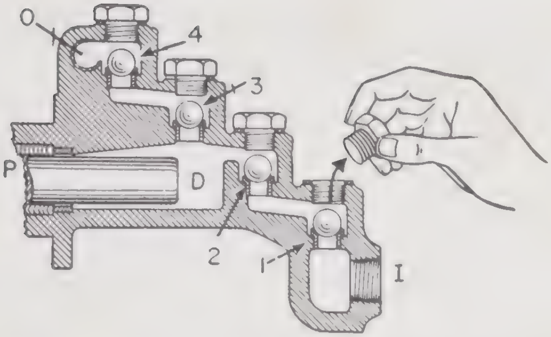
Two of the best types of variable-flow pumps for the food-processing industries are the so-called cradle-mounted tubular type found in the Moyno pumps manufactured by Robbins & Myers, and the step-valve design manufactured by the Milton Roy Company.

Both types can handle practically any pumping job, from free-flowing liquids to highly viscous semi-solids. The Moyno-type pump (see Fig. 20.3) has no cylinder to score, and no pistons and no valves to wear, although its



Courtesy Robbins & Meyers, Inc.

FIG. 20.3. The tubular-type Moyno pump consisting of a helical rotor within a double thread helical stator which develops a positive continuous pumping action



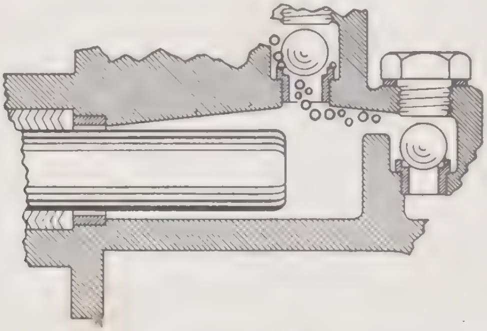
Courtesy Milton Roy Co.

FIG. 20.4. Detail of step-valve pump construction. The suction stroke of the pump plunger *P* draws the liquid in through the inlet port *I*, around the double-ball checks *1* and *2* into the displacement chamber *D*. The discharge stroke of the pump plungers seats the double-ball checks *1* and *2* and raises outlet double-ball checks *3* and *4*, permitting the liquid to flow into the outlet port *O*.

rotor and stator do wear. It pumps with positive displacement and with high reserve pressure without destructive turbulence or agitation. The helical rotor revolves within a double-thread helical stator to produce a continuous pumping action comparable to a piston in a cylinder of infinite length. The pumping action starts as soon as the rotor begins to revolve, and each revolution creates a uniform continuous displacement affected only slightly by discharge pressures. It will pump in either direction with equal efficiency simply by reversing the direction of rotation. It will handle particles up to 0.8 inch diameter in the larger pumps, and has ample pressure to discharge through a screen when breaking down of structures is desirable. Capacities vary from 1 to 150 gallons per minute at pressures up to 1,000 psi.

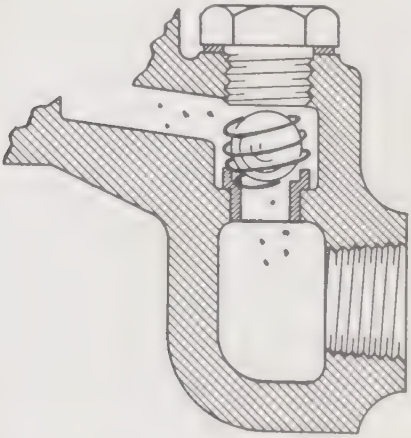
The step-valve pump (see Fig. 20.4) is a reciprocating type designed for precise pumping that will accurately meter liquids in measured volumes against a positive-pressure differential between suction and discharge, with an accuracy within 1 per cent. It is a "controlled volume" pump, rather than a proportioning type, as it will deliver a controlled volume of liquid which may or may not be in proportion to another metered variable. These are not high-capacity pumps, however, although they have capacities ranging from as little as 3 milliliters per hour to 45 gallons per minute at pressures ranging from a few pounds per square inch up to 25,000 psi. Such pumps have wide industrial applications, such as single or multiple units in instrumentation of batch or continuous processes, in blending and formulating feed systems, for automatic concentration control as well as control of flow, liquid level, temperature, pressure or other metered variables.

These pumps handle practically any liquid, from heavy, viscous liquids to light solvents, solids in suspension, abrasive slurries, hot or cold liquids, etc. The suction stroke of the pump plunger draws in liquid through the inlet port, around double ball-checks in the inlet side and in the displacement chamber; it thus creates a partial vacuum, which causes the inlet double ball-checks to rise and rotate from their seats to admit the liquid, while the outlet double ball-checks are seated, preventing back flow. The discharge stroke of the pump plunger exerts pressure on the liquid, seating the inlet double ball-checks and preventing back flow, while the outlet double ball-checks rise and rotate from their seats and permit liquid to flow into the outlet port (see Fig. 20.5). The rotating or spinning action of the ball-checks, together with the pressures exerted during discharge and suction strokes, clear the ball seats as well as provide self-cleaning of the ball-checks themselves. Spinning of the ball-checks also assures they will not seat in the same position, thereby reducing seat scoring (see Fig. 20.6).



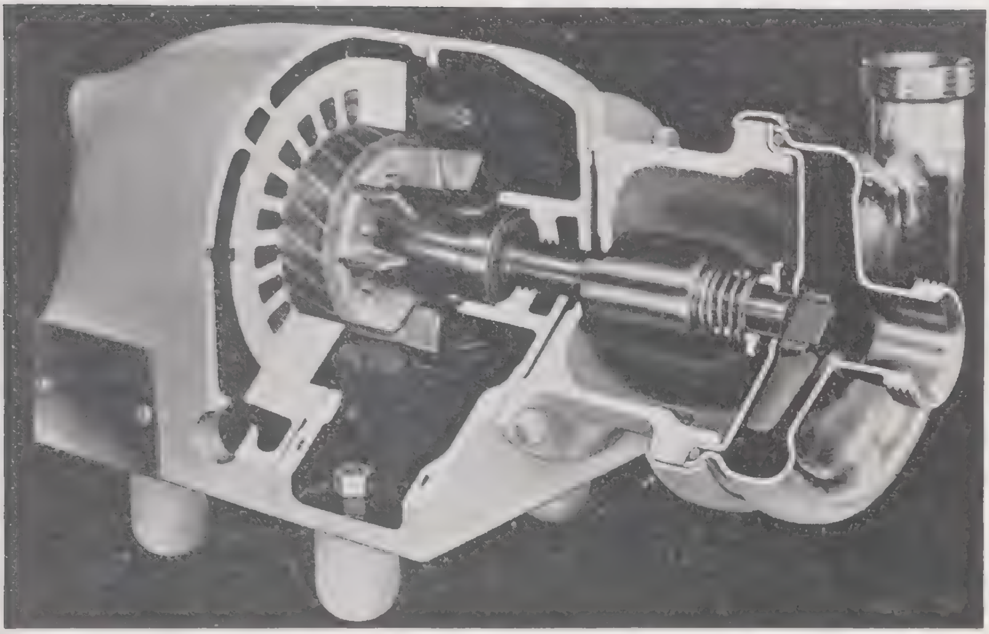
Courtesy Milton Roy Co.

FIG. 20.5. The double ball-checks are snap-acting, open and closed practically simultaneously, and seat positively.



Courtesy Milton Roy Co.

FIG. 20.6. Ball checks are self cleaning and nonclogging, as the spinning action of the balls clears the seats of any lodged particles and assures their not seating in the same position, thereby reducing seat scoring.



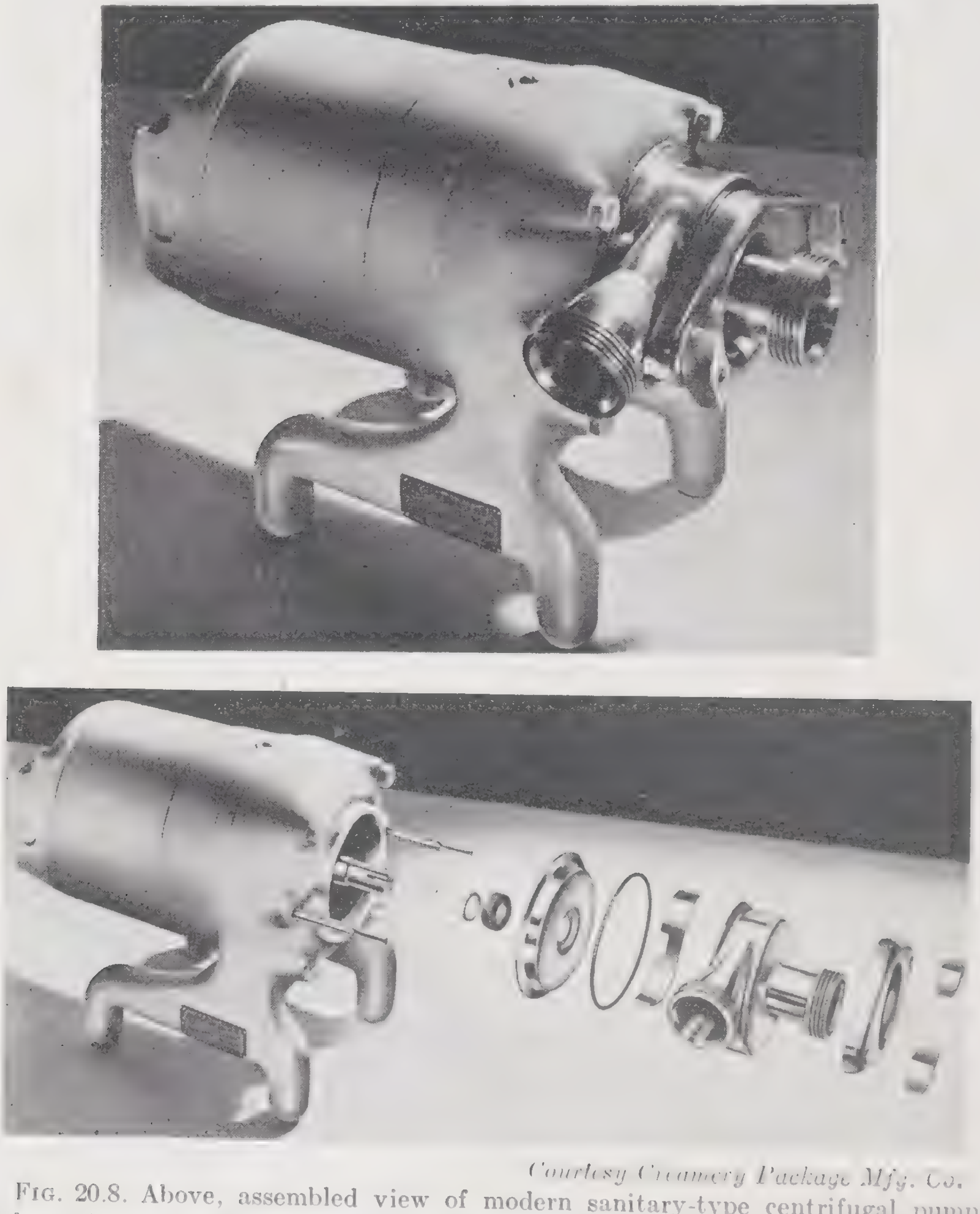
Courtesy Cherry Burrell Corp.

FIG. 20.7. Cut away view of sanitary type centrifugal pump showing casing, impeller, rotary seal, electric motor, and sanitary threaded inlet and outlet ferrules.

CENTRIFUGAL PUMPS

Centrifugal pumps, widely used in the food-processing industries, are of the *nonpositive* type, and are relatively low-pressure pumps that will not build up excessive pressures when discharge valves are closed. Their capacity or output decreases as the pressure increases at constant speed. Centrifugal pumps consist of a rapidly rotating revolving rotor or impeller, shaped so as to impart centrifugal force to a liquid as it passes through the pump; a casing to hold the impeller and liquid; pipe inlet and outlet, stuffing boxes and the necessary driving mechanism (see Fig. 20.7). They give a steady nonpulsating pressure. While this type of pump is used whenever possible because of its relative simplicity and good wearing qualities, it has some disadvantages: it produces high turbulence, with a tendency to "churn the liquid"; it will not give high pressure in a single stage; it is not self-priming; air leaks on the suction side cause considerable trouble; and its efficiency is usually low unless the pump is carefully designed for the service to which it is applied.

The large, clear passages in centrifugal pumps make them relatively satisfactory for handling fluids containing solid particles in suspension, and permit throttling and the temporary closing of the discharge line. The fluid then simply rotates around the casing and absorbs the energy supplied to the impeller; under the proper circumstances, this can quickly raise the temperature of the fluid and pump sufficiently to cause distortion of the rotating parts. In general, a centrifugal pump has lower initial and lower maintenance costs. It is more readily made of materials that resist corrosion than the positive-displacement reciprocating or rotary pumps, but it has less ability to operate with low absolute pressures on the intake or suction. A centrifugal pump is better able to handle viscous liquids than a reciprocating pump, but less so than a rotary pump.



Courtesy Creamery Package Mfg. Co.

FIG. 20.8. Above, assembled view of modern sanitary-type centrifugal pump Below, disassembled "exploded" view. From left to right is motor assembly with shaft, rotary seal spring, rotary metal seal, rotary carbon seal, back plate, gasket, impeller, pump casing, locking clamp, and wing nuts.

SANITARY PUMPS

All three kinds of pumps mentioned above are made in the sanitary type, i.e., so that the impellers, gears or pistons can be easily removed for cleaning, thus making them adaptable for handling food products. The pump may be fitted with a friction seal (see Fig. 20.8) instead of packing. The body and rotors of these pumps are made of white metal, bronze, or stainless steel. Pump housings are also fitted with sanitary pipe connections.

3A Standards as adopted by the International Association of Milk and Food Sanitarians, the U. S. Public Health Service and the Dairy Industry Committee cover some types of sanitary pumps and are of interest from the standpoint of currently preferred designs:

A. *Material.*

(1) All metal pump parts having any surface in contact with the product shall be constructed of dairy metal consisting of stainless steel, nickel alloy, or equally corrosion-resistant material that is non-toxic and non-absorbent.

(a) All milk contact surfaces shall be finished to an equivalent of not less than 120 grit finish properly applied.

(b) All outside surfaces shall be smooth and easily cleanable.

(2) Exteriors of structural parts not in contact with the product shall be of corrosion-resistant material with a smooth finish; or shall be rendered corrosion resistant or painted, and shall be so constructed as to be easily cleanable.

B. *Construction*

(1) All milk-contact surfaces shall be readily removable or accessible for cleaning and inspection. All exterior surfaces shall be self-draining.

(2) The parts forming the space between the motor and the pump body shall be constructed in such a way that they are easily accessible for cleaning and drain freely.

(3) If legs are used, they shall be smooth with rounded ends and no exposed threads. Legs made of hollow stock shall be sealed. On pumps with legs designed to be fixed on the floor, the minimum clearance between the lowest part of the base and the floor shall be 4 inches.

(a) Readily portable pumps not permanently attached may have leg heights of 2 inches. (Readily portable pumps are defined as those having a base area of not more than 1 square foot, or, in the case of motor-mounted pumps, an area encompassed by the legs shall not exceed 1 square foot.)

(b) Bases when used shall be constructed without ribs or flanges and shall have smooth top and bottom surfaces.

(4) Pumps that because of their size and type cannot be mounted on legs shall be mounted on a base designed for grouting and sealing.

(5) The driving means between the impeller or rotor and the pump shaft shall be so arranged as not to form a pocket or crevice that is not readily cleanable.

(6) Threads shall not be in contact with the product.

(7) All surfaces in contact with the product shall have smooth, rounded corners and shall be readily accessible for cleaning.

C. *Openings*

(1) Inlets and outlets shall conform with 3A Sanitary Standards for fittings.

D. *Shaft Seal*

(1) Seal shall be of the sanitary type, easily removable for inspection and cleaning, and shall be constructed of material not injurious to milk.

E. *Gaskets*

(1) Single service gaskets of the sanitary type or removable rubber type gaskets that can be easily cleaned shall be used.

F. *Mountings*

(1) Mountings of motor, pump and drive shall be of sanitary construction and shall either be sealed to the base or mounted to permit easy cleaning with minimum clearance of not less than 1 inch.

G. *Sealing*

(1) Timing pumps used in connection with high-temperature short-time pastuerizing equipment shall be provided with an easily accessible or externally visible seal or seals to limit the maximum capacity of the pump. The seal or seals shall prevent changing the maximum speed of the pump, either by adjustment of the drive or replacement of pulleys or belt.

Figs. 20.2, 20.7 and 20.8 illustrate pumps that incorporate the 3A Sanitary Standards features.

ENGINEERING ASPECTS OF PUMPING AND PUMPS

In using pumps for handling fluids in food-processing plants, it is necessary to estimate several factors before intelligent choice of the proper type and size of pump can be made. Practically all pump manufacturers provide detailed information and engineering data concerning their various types and sizes of pumps. In addition, they also provide maintenance manuals which invariably specify not only the performance characteristics of their pumps but their limitations as well.

In any plant using a multiplicity of pumps, motors, pipes, fittings, etc., the problems of proper maintenance are many and varied. Therefore, the success of any intelligent maintenance (and performance) program can be best insured by preparing a complete maintenance file for each machine used in the plant. Such a file can be placed either in the form of folders or maintenance manuals in a file case or in sturdy loose-leaf binders. In either case, the files should be located in a convenient spot where the operators can readily find them. The suggestions and information contained in most such folders and manuals are intended to be of help in giving the user maximum service of the equipment so described. It might be noted also that they serve a selfish purpose for the equipment manufacturer, as their intelligent use minimizes complaints and unavoidable failures and thereby prevents expense he hopes to be able to avoid. In addition, they can also serve the selfish purpose of reducing losses for the user which might be attributable to improper use of equipment, for example.

Calculating Pump Problems

In calculating pumping problems, a number of formulas and terms are used. Some of the more essential and basic terms to be encountered are as follows:

$$\text{Water horsepower} = \frac{W \times H}{33{,}000}$$

where H = total head including suction lift *plus* discharge lift *plus* velocity head *plus* friction head,

W = weight in pounds of fluid pumped per minute.

This refers to actual work done without considering the pump or motor deficiency.

Suction lift refers to the lift, or height, in feet from the lower level of the liquid to the center of the pump; if the lower level is above the center of the pump, its value must be subtracted.

Discharge lift refers to the lift in feet from the center of the pump to the fluid discharge level.

Velocity head is the head equivalent due to increasing the velocity of the fluid $= \frac{V}{64.4}$, where $V = \frac{0.408 \times \text{gpm}}{D^2}$, gpm being gallons per minute, D being the internal diameter of the pipe in inches and V is the head in feet.

Friction head is the head in feet equivalent of the friction of forcing the fluid through the pipes. These values are obtained from carefully calculated tables such as the data given in Table 14.1, for example; h can also be determined by means of pressure gages installed as in Fig. 20.9, for example.

Note that the suction head as measured by the pressure gage includes the velocity head, when the suction and discharge pipes are of the same size; however, if the discharge pipe is smaller than the suction pipe, then the velocity head will have to be added by taking the difference between the velocity heads in the suction and the discharge pipes. Each pound of pressure is equivalent to 2.31 feet head.

It is also necessary to add in the vertical distance between the suction and discharge gages to the total head accounted for by the gages readings and the velocity head.

To reiterate, the total head in a pumping system is usually made up of the following:

(1) Total static head of discharge above level of suction
(2) Pressure drop through equipment (heaters, filters, etc.) If the pump section is from a vacuum, this value must be added to the total head.
(3) Friction loss through suction and discharge piping.

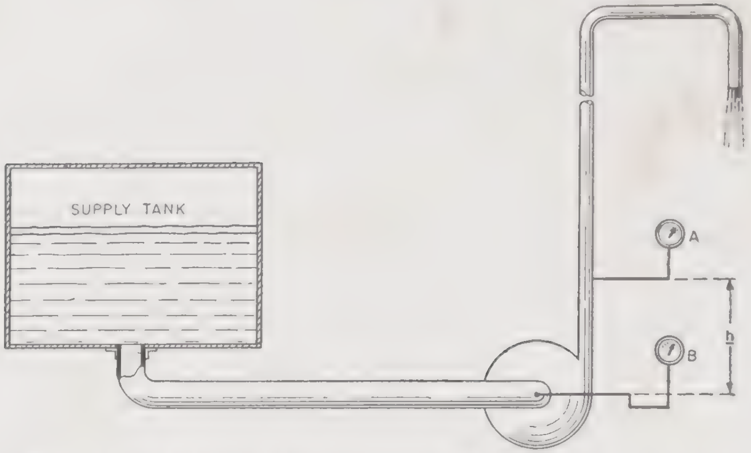


FIG. 20.9. Pump test set-up. The discharge head in feet is determined by multiplying the gage reading at *A* by 2.31 and adding the distance *h* in feet; *h* is the vertical distance from the center of the pump to gage *A*. The suction head is determined by multiplying the reading of *B* by 2.31 and making a correction if necessary for the velocity head in case the suction and discharge pipes of the pump are of different sizes. Note that the suction head may be either positive or negative, depending upon whether the fluid flows into the pump by gravity or is drawn in by suction from a lower level.

In totaling the above figures, any pressure expressed in pounds (psi) must be converted to feet of water by multiplying by 2.31. Any value expressed in inches of vacuum (mercury) must be converted to feet of water by multiplying by 1.13.

Liquids vary widely in viscosity, or consistency. As a result, food-processing industries often need pumps to handle liquids whose viscosities differ from that of water. Liquids with high viscosity resist flow and increase frictional loss. Although very little data have been published, it is known that highly viscous fluids reduce the developed head and the volume as well as increase brake horsepower. Generally, the viscosity of fluids decreases with increasing temperature and increases with decreasing temperature. It is therefore important, when dealing with the pumping characteristics of viscous materials, to consider possible influences of temperature conditions in determining head on pumps.

A typical pumping problem is sketched in Fig. 20.10. In determining the total head loss in pumping milk from a vacuum pan operating under 25 inches of vacuum (mercury) to discharge 10,000 pounds per hour through a cooler into an open holding tank 30 feet above the pump, the friction loss through a cooler has been checked at 5 psi. The pump is located 5 feet below the vacuum pan outlet.

There is a total of 10 feet of 2-inch sanitary tubing on the suction side and 95 feet of $1\frac{1}{2}$-inch sanitary tubing on the discharge side of the pump

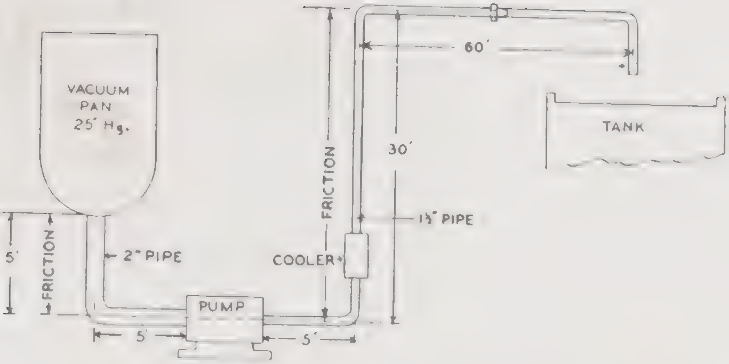


FIG. 20.10. Estimating head on a pump set-up.

TABLE 20.1. FRICTION OF MILK IN 90° ELBOWS IN EQUIVALENT NUMBER OF FEET STRAIGHT SANITARY TUBING

1-in. Ell	1½-in Ell	2 in. Ell	2½ in. Ell	3 in Ell
6-ft Pipe	8-ft Pipe	8-ft Pipe	11-ft Pipe	15-ft Pipe

1-ft head—0.43 psi
1 psi—2.31 ft head

with one 2-inch elbow and three 1½-inch elbows. The solution is as follows:

(1) 30 ft (discharge head) plus[1] 5 ft (suction head) equals	35.00 ft
(2) 25 in. vacuum × 1.13 equals	28.20 ft
(3) 5 psi (friction loss in cooler) × 2.31 equals	11.50 ft
(4) Friction loss of three 1½-in. elbows equivalent to 24 ft of 1½-in. pipe plus 95 ft of 1½-in. pipe gives total of 119 ft 1½-in pipe. Friction loss in 119 ft of 1½-in. pipe is 1.19 × 4.34 equals	5.16 ft
(5) Friction loss of one 2-in. elbow equivalent to 8 ft of 2-in. pipe plus 10 ft of 2-in. pipe give total of 18 ft 1½-in. pipe. Friction loss in 18 ft of 2-in. pipe is 0.18 × 1.11 equals	.20 ft
Total head loss	80.06 ft

The data for the loss of head in feet due to friction per 100 feet of sanitary tubing are given in Table 14.1 as mentioned above. Below is Table 20.1 giving the friction of milk in 90° elbows in the equivalent number of feet of straight sanitary tubing (also for screwed I.P.S. joints) as determined by Tri-Clover Machine Company.

Assuming water was substituted for milk in the example cited above, and further assuming that the total head loss was approximately the same as for milk, the theoretical horsepower required to pump 20 gallons per minute (10,000 pounds per hour) through the system would be calculated as follows:

---

[1] Pump suction is from a vacuum.

$$\text{Water hp.} = \frac{8.34 \times 20 \times 80.06}{33{,}000} = 0.404$$

If the efficiency of the pump used is 55 per cent, the actual horsepower which the motor must supply will be as follows:

$$\text{Motor hp} = \frac{W \times H}{33{,}000} \times \frac{100}{55} = \frac{8.34 \times 20 \times 80.06}{33{,}000} \times \frac{100}{55} = 0.734$$

The capacity of positive displacement piston pumps is given by the formula:

$$\text{Gpm} = \frac{A \times L \times N \times E}{231 \times 100}$$

where A = area of piston in square inches,
L = length of stroke in inches,
N = number of discharge strokes per minute,
E = volumetric efficiency[2] in percentage,
231 cu in. is the volume of 1 gallon.

The capacity of centrifugal pumps is usually estimated on the basis of a discharge velocity of 10 feet per second. A simple formula for approximate calculations on this basis is as follows:

$$\text{Gpm} = 98\ R^2$$

where R is the radius of the discharge pipe of the pump in inches; for example, in a pump having a $1\frac{1}{2}$-inch diameter discharge pipe:

$$\text{Gpm} = 98(0.75)^2 = 98(0.56) = 54.8$$

The characteristics of centrifugal pumps follow several basic laws as summarized below:

$$V = \sqrt{2g\ H}$$

where V = velocity in feet per second,
g = acceleration of gravity (32.2 ft/sec^2),
H = head in feet.

This formula can also be written:

$$H = \frac{V^2}{2g}$$

In considering the centrifugal pump, the velocity V in the formula is the velocity of the outer periphery of the impeller. This can be readily calculated from the diameter of the impeller and its rpm. It is then possible to calculate the theoretical head against which the pump will deliver water if there are no losses. The effect of various pump speeds and impeller diameters can also be determined.

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[2] Volumetric efficiency depends upon design, clearance at the end of the piston, size of valves, suction lift, and temperature of fluid. For cold water in a well designed pump, it should be about 95 per cent.

From this equation it can be shown that

(1) the head (H) varies approximately as the square of the speed;

(2) the quantity varies as the speed;

(3) the power varies as the cube of the speed.

Performance curves should always be obtained from the manufacturer for any pump which is to be used for a service where accurate performance data is essential.

Operational Details of Centrifugal Pumps

Inasmuch as centrifugal pumps are used so commonly in food-processing industries, it would probably be helpful at this point to emphasize certain features with reference to the suction and discharge piping.

The suction piping should be simple, with as few sharp turns as possible. Where it is necessary to use a long suction line, the size of piping should be increased. For most efficient operation the suction piping should never be of less diameter than the pump suction opening. It should preferably be larger. When the suction piping is larger than the pump opening, a tapered eccentric reducer should be installed, as shown in Fig. 20.11. The suction line should be designed so that air pockets cannot form in it. Proper support should be provided for the pipe and fittings to avoid undue strain on the pump. All joints should be aligned and tightened properly so that no air can leak into the pump, as air reduces its capacity and may even cause it to stop pumping.

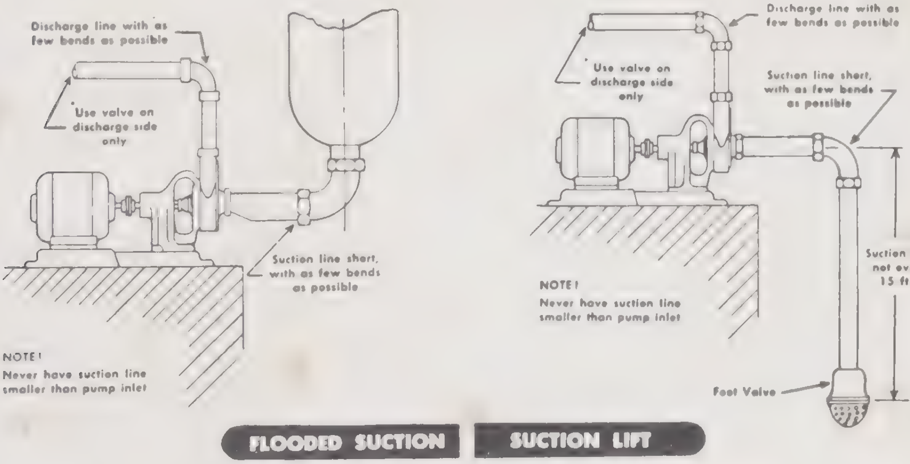

Discharge line with as few bends as possible
Use valve on discharge side only
Suction line short, with as few bends as possible
NOTE!
Never have suction line smaller than pump inlet
Discharge line with as few bends as possible
Use valve on discharge side only
Suction line short, with as few bends as possible
Suction lift not over 15 ft
NOTE!
Never have suction line smaller than pump inlet
Foot Valve
FLOODED SUCTION
SUCTION LIFT

FIG. 20.11. Installation details of centrifugal pumps.

A centrifugal pump can lift liquids a considerable distance, but for most efficient operation the suction lift should not exceed 15 feet. Where it is necessary to operate a centrifugal pump with a suction lift, it will be necessary to prime the pump with liquid. To be sure that the liquid will not drain off into the supply tank or source, a foot valve must be installed at the bottom of the suction line.

In centrifugal pumps only, a shutoff valve is sometimes used to throttle or shut off the pump. Never use a valve in the suction line for this purpose.

The discharge head on a pump is the sum of its vertical head plus the head developed by friction loss in the discharge and suction pipes and equipment, such as filters, heaters, and the like. In pipelines where an excessive number of elbows and bends are used, it is entirely possible that the friction loss in these fittings may be greater than in the pipe itself. It is therefore sound economy to install the discharge line with as few turns and elbows as possible. Never use a smaller discharge line than the pump outlet without a recommendation from the manufacturer.

Where a larger discharge line is used than that recommended, the decreased friction loss may reduce the total pump head, thereby increasing the pump volume. In some cases, this increased volume may cause pump vibration due to cavitation, and may also overload the motor.

In milk applications it is desirable to eliminate a discharge valve for throttling purposes. It is absolutely essential that the total pump capacity at a given head be equal to the operating condition, and this may require a cut-down impeller to meet required conditions. The reason for this is that milk technicians feel that a throttling valve installed for the purpose of cutting down the volume or eliminating cavitation may cause texture defects in milk and cream.

When centrifugal pumps develop operating difficulties, the following check list will be found helpful in locating the causes:

Nature of Trouble	*Items to be Checked**
1. No product delivered	a - b - c - d - e - f - g - h - i
2. Pump not delivering up to capacity	a - b - c - d - e - f - g - i - j - k - l
3. Discharge pressure too low	b - e - g - l - m
4. Pump delivers for awhile and then quits	d - f - g - i
5. Pump requires too much power	e - n - o - p - q - r
6. Pump noisy when running	d - q - r - s - t - u - v

* Notations refer to items listed below:

(a) Pump not properly primed; casing and suction line must be completely full of fluid.

(b) Pump speed too low; check voltage across motor terminals to see that it is no more than 10% lower than it should be.

(c) Discharge head too high; check, including friction loss.

(d) Suction starvation; suction tubing may be too small, too long, or may contain too many fittings. Excessive friction loss may be the result. Relocate pump if necessary.

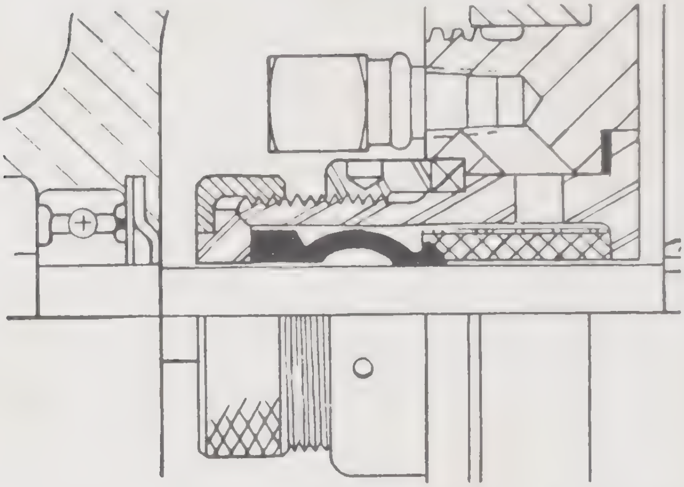
(e) Wrong direction of rotation.
(f) Air pocket in suction line.
(g) Air leak in suction line or rotary seal.
(h) Suction line completely plugged.
(i) If product is hot or volatile, there should be suction head on the pump.
(j) Suction line partially plugged.
(k) Impeller too short.
(l) Impeller damaged.
(m) Impeller wrong size.
(n) Speed too high.
(o) Discharge head too low; pump handling too much product; impeller may be too long.
(p) Product may be too heavy for motor; check viscosity and specific gravity.
(q) Shaft may be bent.
(r) Impeller may be binding.
(s) Fastenings may not be tight.
(t) Impeller may be broken.
(u) Impeller may be unbalanced.
(v) Motor bearings may be worn.

Selection of Pumps

The type and design of pump will be determined by resort to several factors of selection including (1) the need for either a positive or nonpositive displacement; (2) the pressure needed and whether it should be steady or pulsating; (3) the necessity of self-priming; and (4) the sanitary demands. The material used in construction should be such that it will withstand the pressures likely to be encountered. The metals used in construction must be selected with due regard to tendencies to corrode, erode or cause flavor changes in the food materials with which they will be in contact.

In view of the increasing emphasis upon sanitary construction in pumps handling liquid foods, the matter of stuffing boxes or rotary seals must be considered. In general, a graphited square flax packing is suitable for water and brine systems; composition high-pressure graphited packing for steam and ammonia systems; and rubber or plain square flax for certain liquid foods. Water-cooled rotary seals are used in pumps handling milk, for example, in high-temperature or vacuum-pan operations. Construction is similar to that of the packing gland pump, with the exception of the sealing medium. Instead of packing, it utilizes the rotary seal which is backed against a carbon ring (see Fig. 20.12).

In the water-cooled rotary seal construction, water from an outside source is supplied to the seal housing through an inlet elbow and discharged through an outlet elbow. This water, under fixed pressure, floods the seal, keeping it cool and vacuum-tight. The amount of water flowing through the seal may be controlled by a pressure regulator supplied with the pump,



Courtesy Tri-Clover Machine Co.

FIG. 20.12. Water-cooled rotary seal detail. Construction is similar to that of th packing gland except that it utilizes the rotary seal backed against a carbon rin (shown in solid black) instead of packing.

or by a small control valve which can be shut down until the desired amount of water runs through the seal. About three gallons of water per hour wil reduce the temperature in the seal to approximately 100°F when the temperature in the pump is 175°F. Proper design will provide sanitary features applicable to high-temperature handling of milk or other liquid foods; it will also prevent the water used as cooling medium from entering the product zone.

Other types of rotary seal construction utilize inert carbon elements that rotate with the shaft of the pump usually held up snug against the casing by spring tension (see Fig. 20.13). Either paper or rubber gaskets are used in sealing the pump cover and back plate with or without cover clamps (see Fig. 20.14). The more modern and sanitary types of centrifugal pumps now used in food-processing operations fully assembled and in "exploded" detail are shown in Fig. 20.8.

Flour Fluidizing and Pumping

In the bulk handling of flour, bulk trailers and a newly developed flour-fluidizing and pumping system has found considerable favor[3]. The individual filling, handling and dumping of bagged flour involves considerable costs between flour mills and bakeries, for example. Loading and unloadin 100-pound sacks is a back-breaking job while dumping the bags is slow and unpleasant as well as hazardous due to the flour dust thus developed.

The essential difference between this system of flour handling and con-

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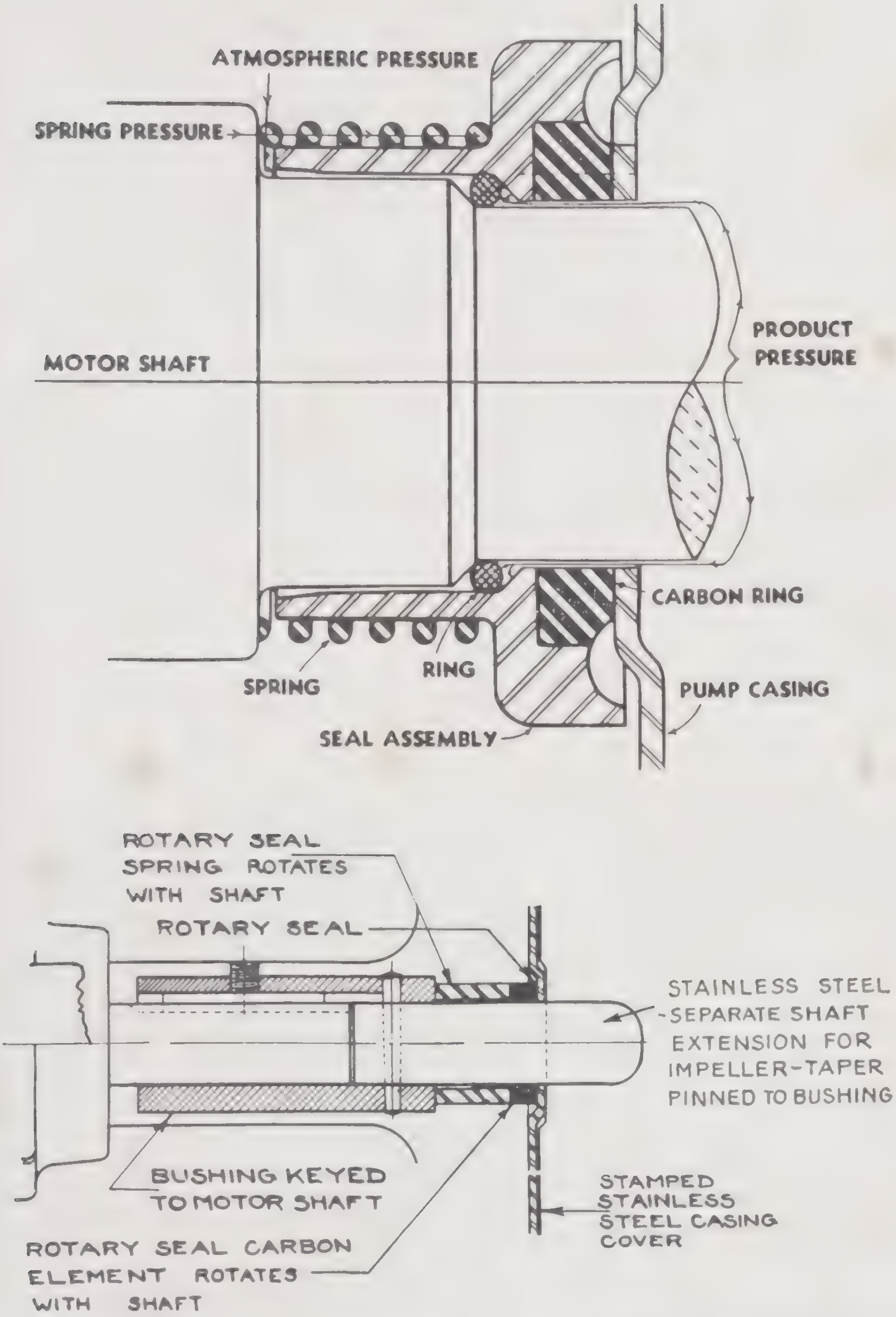
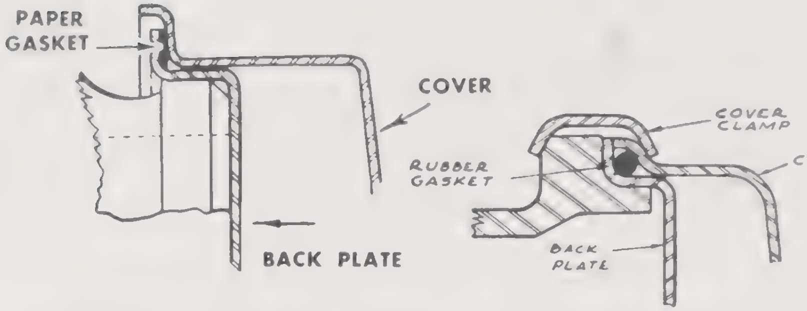
[3] *Food Processing*, **14,** 8, 32–33 (1953).


ATMOSPHERIC PRESSURE
SPRING PRESSURE
MOTOR SHAFT
PRODUCT PRESSURE
CARBON RING
SPRING
RING
PUMP CASING
SEAL ASSEMBLY
ROTARY SEAL SPRING ROTATES WITH SHAFT
ROTARY SEAL
STAINLESS STEEL SEPARATE SHAFT EXTENSION FOR IMPELLER-TAPER PINNED TO BUSHING
BUSHING KEYED TO MOTOR SHAFT
STAMPED STAINLESS STEEL CASING COVER
ROTARY SEAL CARBON ELEMENT ROTATES WITH SHAFT

Courtesy Cherry Burrell Corp.

Fig. 20.13. Rotary seal assemblies detail used in sanitary type centrifugal pumps.

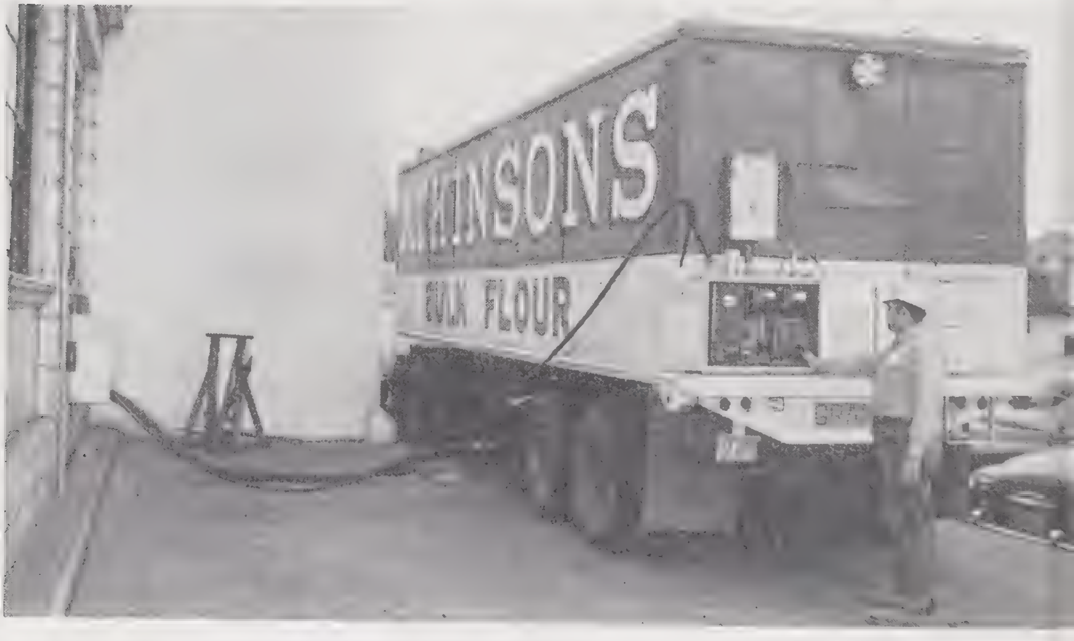


Courtesy Cherry Burrell Corp.

FIG. 20.14. Gasket assembly detail for sanitary-type centrifugal pumps.

ventional pneumatic systems is that a smaller amount of air does more work, with a minimum of aeration. This new method developed by the Atkinson Bulk Transport Company of Minneapolis, Minnesota, requires approximately one pound of air to move 50 to 80 pounds of flour in contrast to ordinary systems requiring one to three pounds of air for each pound of material moved. Because of the low operating pressures (5 to 13 psi), filtering is merely a matter of providing a flannel cloth at the air intake of the pumping actuator located on the transport truck (see Fig. 20.15), and the air discharge point located within the plant. The actuator pumps the flour, in a fluidized state, rather than blowing it.

Both working and sanitary conditions within a bakery plant are tre-



Courtesy "Food Processing"

FIG. 20.15 Bulk flour actuator is located on truck trailer for pumping fluidized flour. Bakery needs only pipe and storage facilities.

mendously improved as one man easily handles flour receiving, transporting the movable bins via fork trucks to an automatic inplant conveying system, for example. Not only is the cost of flour reduced since this fluidized-flour pumping method can also be used at the mill but it is reported to have the added advantage of facilitating mixing operations accompanied with noticeably improved bread quality.

Section III

Conversion of Raw Materials

21. Mixing

Mixing is involved in almost every step of food processing, although in most of the applications of this unit operation, surprisingly little attention is paid to some of the basic theoretical considerations involved. In other words, in most cases there is an apparent disregard of ideal mixing conditions. The fact that mixing is often carried on simultaneously with other operations, such as extraction, churning, grinding, heat exchanging and packaging, tends to obscure its fundamental characteristics.

A number of terms are associated with the mixing of materials. *Agitating* usually refers to the mixing of relatively low-viscosity liquids by means of comparatively high-speed devices. Recent technological advances in the thermal processing of canned food products have emphasized the advantages of agitating, or mixing, the contents as a means of expediting heat transfer. *Kneading*, or working, refers to the mixing of liquid or semisolid masses of high viscosity. The mixing of solids is often called *blending*, although it is also applied to the mixing of fluids, usually in connection with special or unusual flavor developments or enhancements. The preparation of stable emulsions is frequently called *homogenizing*, although we have already emphasized its classification as an important disintegrating operation.

The chemical engineer regards (1) the intimate contact of reacting surfaces and (2) the maintenance of uniform concentrations and temperatures in a reaction mass as of primary importance in the conduct of any chemical reaction he is concerned with, and he relies on mixing to provide these. But the food engineer has the added concern not only of taste and odor but also of body, texture, color, appearance and other decisive acceptability factors. Mixing is a unit operation of primary importance, as well as being an adjunct to other operations having a wide range of objectives. It therefore deserves the most careful and exhaustive study of its theoretical considerations.

Normally, mixing operations involving two states of matter should be classified according to the nature of the continuous phase or of the preponderant one, even if it is not continuous. Mixing techniques, therefore, are basically those concerned with the mixing of materials with (1) gases,

(2) liquids, and (3) solids. The major food-mixing problems are those concerned with the following three subdivisions: (1) mixing of liquids; (2) mixing of viscous liquids and pastes; (3) mixing of dry powders, but including such operations as (a) mixing of miscible liquids; (b) dilution; (c) solution of a solute in a solvent; (d) fining; and (e) suspension for reaction. However, as an adjunct to packaging operations we do occasionally encounter the mixing of materials with gases, which suggests we cannot ignore these rather exceptional cases.

MIXING OF MATERIALS WITH GASES

In food packaging, there has been a growing reliance on the techniques of gas mixing, especially since World War II. Those techniques are relatively simple if one gas is already present in a container, as the mere introduction of a second gas through an inlet pipe or nozzle will usually prove fully adequate to produce a uniform mixture rapidly. A centrifugal-type fan, mounted either internally in a tank or chamber, or externally with ducts leading from the tank to the fan and back to the tank or chamber, will give very satisfactory mixing, whereas if two gases are brought together in a moving stream, complete blending is achieved almost instantaneously to provide a continuous mixing operation. From these observations, it will be obvious to the reader that no appreciable problems of gas mixing as such are likely to be encountered in food packaging. Nevertheless, in the gas packing of certain foods (mixing solids with gases), the adequate displacement of any residual or occluded air or oxygen is often essential to proper quality control. Usually gas packing of foods involves first evacuating the container of its normal air content and then displacing it with an appropriate gas or gases, such as carbon dioxide or nitrogen, or both. Also in food packaging we encounter the problem of mixing a gas (carbon dioxide) with a liquid (sweetened and flavored water) as in the carbonation of beverages, which will be discussed later.

In food packaging, there are probably no circumstances requiring mixing a liquid with a gas, or more specifically, dispersing a liquid in a gas. Such an operation is essential in spray-drying techniques, to be sure, but not as a means of promoting the production of a food product. In other words, gases are dispersed in food products, both liquid and solid, but we do not disperse liquid or solid food materials in gases before they are consumed, except in a processing technique like drying. The mixing of solids with gases is never utilized in food processing—in fact, every effort is taken to prevent this in food plants in order to (1) minimize entrainment losses and (2) avoid explosion hazards, such as the critical dispersion of starch particles in the atmosphere in a confectionery plant, for example.

While the foregoing discussion of mixing materials with gases has been somewhat brief, it has been adequate, as the actual mixing of gas with gas in packaging does not present any practical difficulties per se. The natural diffusion of gaseous molecules and the convection currents which always seem to be present in gas masses will cause mixing, slowly perhaps, but certainly. Consequently, there is not necessity for concern about the intimate mixing of two or more gases, even with the simplest of mixing devices.

MIXING OF MATERIALS WITH LIQUIDS

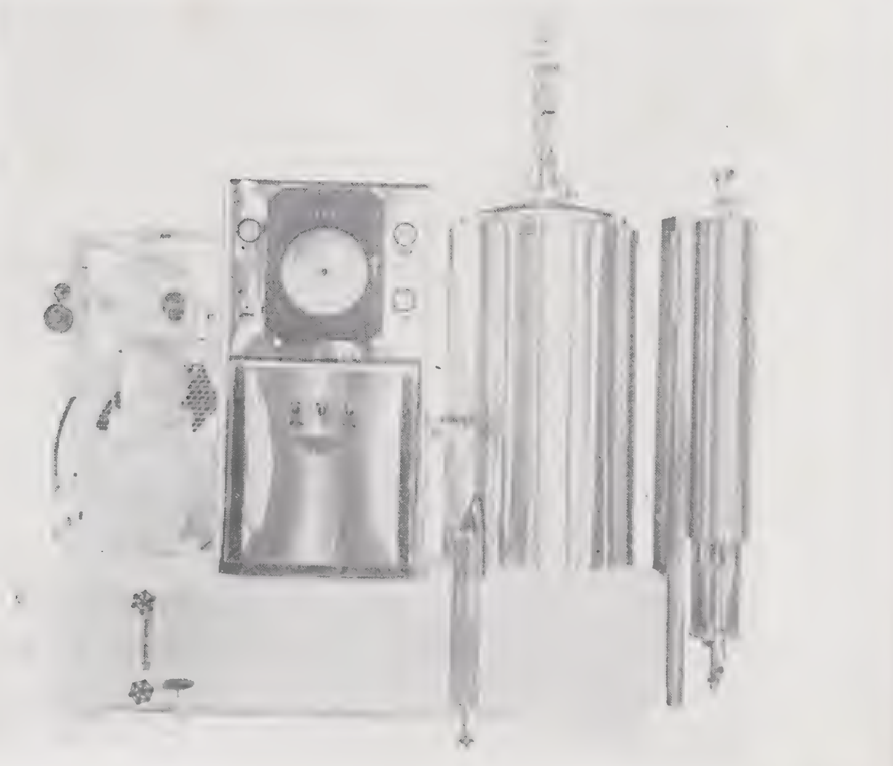
It is frequently necessary to add a gas to a liquid food as an accessory in conjunction with preservation (e.g., carbonation of beverages) or separation (e.g., churning of cream); to produce a physical suspension of gas in the liquid (e.g., foam), which will last long enough for the liquid to be solidified around the gas bubbles (e.g., baked bread, frozen ice cream or ripened cheeses); and to form semipermanent dispersions of gases in high-viscosity liquids found in many modern food preparations (e.g., marshmallows). Since the techniques involved in this type of operation are markedly affected by the viscosity of the liquid medium, any consideration of the techniques of mixing must take this fact into account. Where the operation requires the initial contact of gas and liquid, it is generally more satisfactory to disperse the gas through the liquid than the reverse. Exceptions to this rule are where it is necessary to bring a small amount of the liquid into large volumes of gas (e.g., drying), providing thereby an unusually large surface area per unit quantity of the liquid.

Mixing of Gases with Liquids of Low Viscosity

The mixing of gases with liquids as a batchwise operation is occasionally necessary in food-engineering practice. Probably the simplest of all methods of mixing a gas with a liquid is to introduce the gas at the bottom of the tank containing the liquid food and to permit it to bubble up through the liquid. A sparger pipe or fitting to break up the gas into fine bubbles and to distribute them more or less uniformly over the entire horizontal cross section of the liquid improves the contact. If the time of contact between the liquid and gas is too short in a single pass, the tank may be closed and the gas collected at the top, drawn off by a pump, and reintroduced (with fresh make-up of gas) at the bottom of the tank. Additional contact area can be obtained by simultaneously removing liquid from the bottom of the tank and spraying it into the gas space at the top. Mechanical agitators are also used to distribute gas throughout a liquid. A closed-vane turbine mounted on a hollow vertical shaft can be used to draw gas down through the shaft and discharge it horizontally into the liquid, the liquid being simultaneously agitated by the turbine impeller. Fresh gas can also be introduced to the gas space above the surface of the liquid or through a separate gas inlet bubbler near the bottom of the tank.

One of the most common mixing operations encountered in food processing is the problem of mixing a gas with a liquid, as in the carbonation of beverages. The volume of gas in the finished product is a most important factor, as the amount of gas dissolved in the beverage controls not only its degree of "sparkle" but its keeping quality and general acceptability as well. It is common practice to mix carbon dioxide gas with the beverage by means of a carbonator (see Fig. 21.1), which provides for the exposure of a large surface of the liquid to the gas under pressure, thus enabling the liquid to absorb the gas quickly. According to Henry's Law, the volume of a gas dissolved in or absorbed by a liquid is proportional to the pressure of the gas at constant temperature. This law is, however, conditioned by the nature of the molecule as it exists as a gas and as it exists in solution. In the case of carbon dioxide, as far as carbonated beverages are concerned, however, such variations in Henry's Law are not of great moment and do not need to be considered further.

When the pressure of the carbon dioxide is one atmosphere (14.7 psi) it



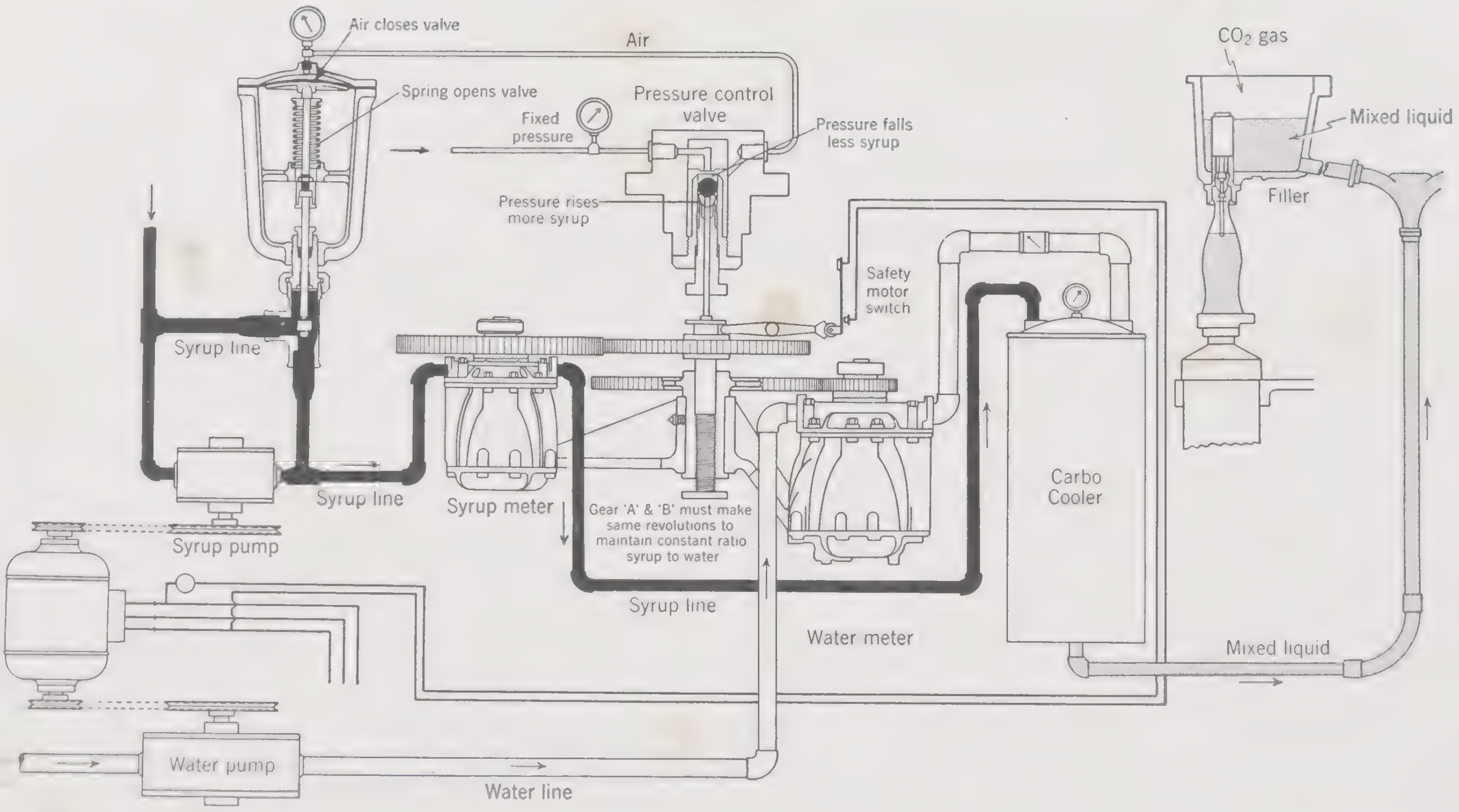
Courtesy Mojonnier Bros. Co.

FIG. 21.1. A combined carbo cooler and syrup cooler—water cooling, carbonating and syrup cooling in a single-package unit.

will dissolve in an amount governed solely by the temperature of the water. The unit of measurement which has been adopted as standard is the *volume*, defined as the amount of gas in milliliters that a given quantity of water will absorb at atmospheric pressure and at 60°F. This condition registers zero on the gages normally used to measure the volumes of carbon dioxide absorbed. Thus at 60°F water will absorb 1 volume of carbon dioxide, represented as 0 on the gage. When the pressure is increased to 2 atmospheres (29.4 psi) water will absorb 2 volumes, and for each additional 15 pounds of pressure an additional volume of gas will be absorbed. When the temperature of the water is reduced to 32°F, 1.7 volumes of carbon dioxide will be absorbed, and for each additional increase of 15 psi there will be an additional absorption of 1.7 volumes of carbon dioxide. Hence, if a bottle was filled at 32°F under 30 psi gage pressure, the volume of carbon dioxide absorbed would be $1.7 \times 3 = 5.1$ volumes. At intermediate temperatures and pressures, intermediate volumes will be absorbed. Generally, carbonated nonalcoholic beverages contain from 3 to $4\frac{1}{2}$ volumes of carbon dioxide.

In passing, it should be pointed out that the carbonated beverage industry is vitally interested in the characteristics of the water it uses, since water constitutes such a large proportion of its finished products. To be considered suitable for beverage purposes, a water must be of unimpeachable sanitary quality; it must be free of suspended matter and coloring materials; it must be clear and not contain excessive mineral or other substances which may affect the flavor or give rise to objectionable tastes and unsightly deposits in the finished product; and it should preferably be of low alkalinity. Practically all commercial carbonated nonalcoholic beverages today are prepared from carefully treated and purified waters, as well as by standardized formulas using specific ingredients that are subject to rigid quality control. The degree of care exercised in all aspects of carbonated beverage manufacture is demonstrated in the fact that a product such as Coca-Cola tastes the same, irrespective of the locality in which it is produced.

Actually, the filling (packaging) of beverage containers involves basically controlled methods of syrup and water treatment, preparation, handling and filling (the mixing of liquids with liquids), as well as their carbonation within the container (the mixing of liquids with gas). In the beverage filling (packaging) process illustrated in Fig. 21.2, filtered and deaerated water as well as prepared syrup are simultaneously cooled and carbonated in the so-called Carbo Cooler, which eliminates separate water coolers, carbonators and mixers. Both the syrup and the water are accurately measured by separate meters in the correct proportions of the finished product. The metered fluids are pumped into the Carbo Cooler, where they are mixed



Courtesy Geo. J. Meyer Mfg. Co.

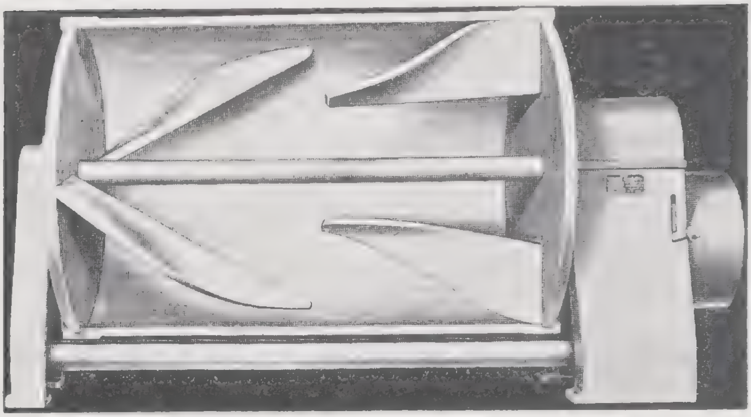
FIG. 21.2. Diagrammatic stretch showing operation of an automatic metering beverage cooling, carbonating, and filling system.

and cooled to the desired temperature for carbonation with the required volumes of gas for the finished beverage. The mixture of syrup and water is carbonated just as readily as the water, and their simultaneous processing gives a uniformly mixed drink, ready for running into the bottle. Obviously, clean and practically sterile bottles or other containers are essential to successful processing. The cooled, carbonated beverage flows into the bottle from a filler bowl through a sanitary type valve which operates on a counter pressure principle to assure uniform filling height. The crowner (container sealing) unit is an integral part of the filler. No mixing or tumbling devices are required after sealing the filled container, because the mixed carbonated beverage is the finished product, ready for consumption.

A gas is frequently blended with a liquid by introducing the two simultaneously to the inlet of a centrifugal pump; where a single pass does not provide sufficient contact time, two or three pumps in series may be necessary to provide the required contact. The aspirator is an ideal pump for introducing gas into a liquid, while a mechanical mixer of the turbine type can also be used for continuous blending of gases with liquids. Such turbomixers, as they are often called, provide a series of mixing compartments through which the liquid slowly passes; here it is brought into contact with new gas bubbles in each compartment, the liquid itself being passed either upward or downward through the unit. There are several types of towers in which liquid and gas are brought into contact by spreading out the liquid into thin layers, by dispersing it in small droplets which fall through the gas, by repeatedly breaking up the gas stream into small bubbles as it passes upward through the liquid, or by various combinations of these methods. These various devices for the mixing of gases with liquids of low viscosity are extensively used by chemical engineers, but have not been utilized as widely by food engineers, as about the only application they are confronted with in food processing is the carbonation of beverages.

Mixing of Gases with Liquids of Medium Viscosity

The mixing of gases with liquids of medium viscosity (up to the consistency of heavy syrups or pastes) presents more difficult problems, as the techniques of bubbling air through the food mass are not usually practical, air being the gas usually incorporated in processed foods. Whippers and beaters (similar in construction to the domestic egg beater) are commonly used; these either fold gas into the liquid by having the stirring elements lift up and out of the liquid mass, or churn the gas into the liquid by pulling it between rapidly rotating blades. The conventional butter churn is usually a large-diameter barrel or drum provided with inner baffles for whipping air into the cream to form a foam, which is an essential prerequisite before the butterfat globules will "gather" to form butter granules or "butter corn."



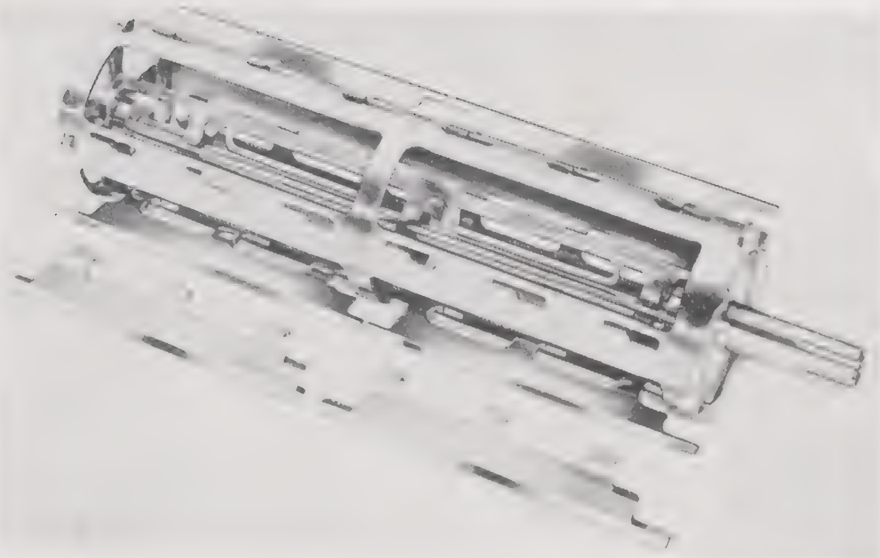
Courtesy General Dairy Equipment Co.

FIG. 21.3. Cut-away diagram of the vane churn. Each vane is so shaped that it lifts and kneads ("works") the butter masses always toward the center of the churn. The bar across the center splits the butter masses as they fall, thus kneading them still more.

The earlier butter churns were provided with internal rolls which were set in motion to "work" or knead the gathered butter granules, moisture and salt into the mass of finished butter containing the proper proportions of moisture and salt. More recent designs of butter churns have dispensed with inner rolls and depend upon the fall of the butter mass onto a splitting bar and vanes or shelves within the barrel to knead the butter properly (see Fig. 21.3).

In the manufacture of ice cream, the added volume of the ice cream over that of the original mix (expressed as "overrun") consists of air, which is incorporated or whipped into the ice cream as it passes through the freezers. While the amount of incorporated air is subject to precise control by certain pressure-regulating means, the actual mixing of gas (air) with the basic cream mass (whose viscosity is being simultaneously increased by the lowering of its temperature during freezing) is accomplished by a motor-driven dasher within the freezing unit. Fig. 21.4 shows a unique reaction-type unidirectional beater which is mounted off center and turns by the reaction caused by the increasing stiffness (viscosity) of the freezing cream mass within the ice-cream freezer unit.

We have mentioned whippers and beaters which churn the gas into the liquid by pulling it between rapidly rotating blades. One type involves the fixed suspended agitator. This may consist of a power-driven shaft upon which has been attached one or more propellers, centrally disposed so as to provide maximum incorporation; or it may consist of a power-driven shaft with one or more propellers attached, but with the agitator affixed to the side of the tank and positioned at an angle and off center, to provide a fold-



Courtesy Creamery Package Mfg. Co.

FIG. 21.4. Continuous freezer dasher of stainless steel construction and sanitary design with two of its scraper blades dissembled. Note the off center location of the beater blades.

ing action in incorporating air or gas. There is also the double-action agitator with or without scraping blades, the shafts of which operate in opposite directions. In addition to the propeller-type agitators which are widely used, there are the relatively slow-speed paddle agitators that sweep the bottom of a container or tank, and are simple in design as well as low in cost, upkeep and power consumption. A paddle agitator with multiple blades, either horizontal or vertical, is called a gate agitator, both styles of which are used in modified designs too numerous to discuss.

Mixing of Gases with Liquids of High Viscosity

We know of no cases other than those mentioned in the foregoing discussion of the mixing of gases with liquids of medium viscosity where the incorporation or mixing of gases with liquids of high viscosity is normally encountered in food processing. Possible exceptions to this statement are the mixers used in the production of special confections, such as marshmallow beaters. While there are devices for the mixing of pastes and viscous liquids, any incorporation of air or gas is coincidental, and is not intentional or desired.

Mixing of Liquids of Low Viscosity

If the liquids to be blended are of low viscosity, have nearly the same specific gravity and are mutually soluble, complete mixing is relatively easy.

If the opposite situation prevails, mixing may require powerful mechanical devices which are expensive to buy and to operate. The methods of mixing liquids with liquids involve materials of widely different properties and the equipment utilized is quite variable in design.

Two liquids brought together in a tank or vat may be mixed by high- or low-speed mechanical agitators, by outside circulation, or by air agitation. Two general types of high-speed agitators are available, both quite suitable for the mixing of low-viscosity liquids. The most popular are the several forms of propeller mixers. The propellers may be introduced into the liquid from the surface on a vertical or nearly vertical shaft, or may be attached to a shaft which is led into the tank through a fitting on the side of the tank.

Propellers or agitators installed through the bottom or the side of tanks should be constructed of smooth, corrosion-resistant metal, have rounded corners and be connected to the shaft by welding. The shaft should be removable at a point outside the tank. The opening in the tank bottom or side which accomodates the shaft will make cleaning difficult unless an all-metal seal of the rotary seal type or a carbon seal of the packing-gland type described in Chapter 20 is provided. The use of packings of leather, cotton, felt, asbestos and other similar material makes the use of a submerged agitator definitely undesirable in food processing; this should not be tolerated with liquids of low viscosity under any circumstances.

Heretofore, the mixing of liquids with propeller agitators has generally been limited to using two or more propellers on the same shaft, or a similar number on different shafts. Another expedient has been to use propellers operating at different speeds, in opposite directions, or of different pitches to improve the agitation of a liquid within a tank. Exhaustive studies of liquid mixing technology by Rushton and his students have pointed the way to more efficient mixing practice based upon sound scientific and engineering principles. Accordingly, we have outlined in the subsequent paragraphs some of the more salient factors which should be kept in mind in considering efficient liquid mixing practice[1].

In liquid mixing operations the liquid is moved by rotating impellers. The flow path, velocity, and quantity are dependent upon the shape and position of the impeller, the shape of the container and its fittings, and on the physical properties and boundary positions of the liquid. As a result of operating experience and compromise between many practical and economic considerations, best practice may be generalized as follows:

The mixing tank should be cylindrical with axis vertical; the bottom may be flat, dished out, or shallow cone. Liquid depth equal to tank diameter is good practice, but it may be as deep as two diameters. In large-diameter tanks the liquid depth is less, but good mixing cannot be obtained if the liquid is too shallow. The following minimum liquid depths are recommended as low limits:

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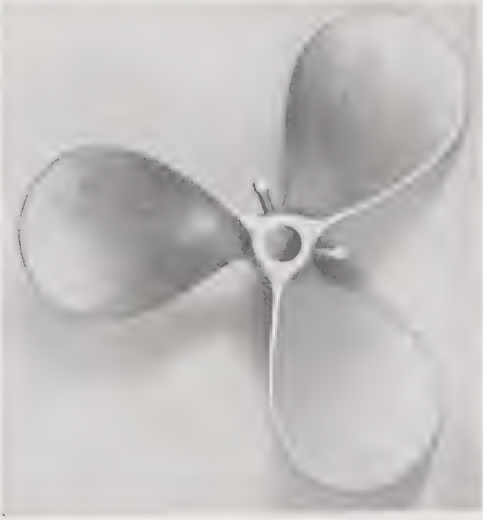
[1] Rushton, J. H., and Oldshue, J. Y., *Chem. Eng. Progress*, **49**, 161, 267 (1953).

Maximum ratio of tank diameter to minimum liquid depth	2	3	4	5	7
Minimum liquid depth in feet	1	1 to 5	5 to 10	10 to 15	15 to 20

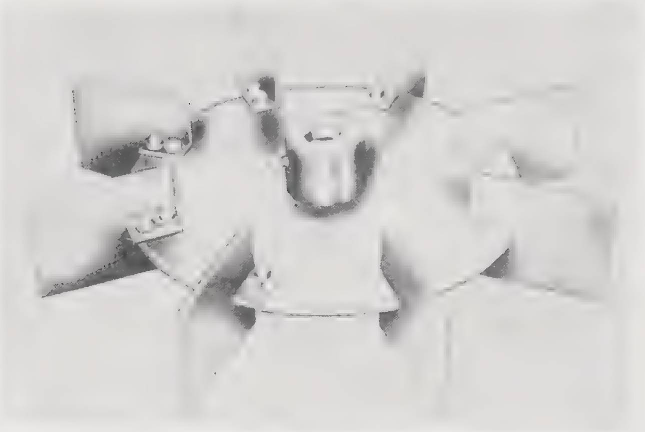
Square or rectangular tanks are avoided because it is often difficult to secure adequate fluid motion in the corners.

Mixing impellers used to produce flow and turbulence are rotating impellers such as the marine-type propeller (Fig. 21.5), the turbine (Fig. 21.6), and the flat paddle (a flat rectangular solid plate with a hub at the middle for attaching to a rotating shaft). There are many variations in design from these common impellers; the answer to most mixing problems, however, does not lie in some unusual impeller form, but rather in knowing the type of fluid flow and turbulence resulting from different impellers, fluids, and containers, and the flow pattern best suited to a particular mixing problem. Impellers are usually about one-third of the tank diameter, and if only one is on a shaft, it is placed approximately one impeller diameter from the bottom.

When two or more impellers are on a shaft, they are placed at least one impeller diameter apart. Impellers are rarely placed closer than one diameter to the liquid surface unless gas is to be drawn in through the surface.



Courtesy Mixing Equipment Co., Inc.
Fig. 21.5. Marine-type impeller.



Courtesy Mixing Equipment Co., Inc.
FIG. 21.6. Flat-blade turbine impeller.

Vertical shafts with impellers are placed on the center line of the tank, and baffles are used at or near the tank walls, or sometimes near the impeller. Occasionally a baffle is used across the bottom of the tank or horizontally across the liquid surface. Propellers are often used in an off-centered position (Figs. 21.10 and 21.11) without baffles, and the shaft may enter through the top of the liquid or through the side wall.

The liquid to be mixed is given by the nature of the problem, and little can be done to change its physical properties to make them more favorable to the desired mixing operation. It is easier to mix liquids of low viscosity and density. Turbulence spreads more rapidly in low-viscosity liquids, and less power is required to produce rapid mixing than for high-viscosity liquids.

Flow Patterns for Mixing. The impeller causes fluid motion and, together with the wall, generates the principal lines of flow through the liquid. When a single impeller of any shape or size is rotated on the center line of a smooth-wall cylindrical tank, the flow motion set up is a rotary swirling or

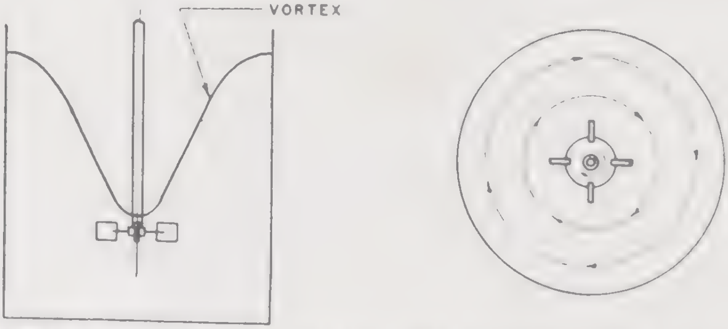


FIG. 21.7. Flow motion in a cylindrical tank without baffles. Vortex is formed with a turbine, a propeller, or any shape impeller. Left, side view; right, bottom view.

vortex motion (see Fig. 21.7). The flow is circular and there is practically no vertical motion. Since the liquid swirls as in a merry-go-round, there is little chance for mixing, because liquid is not forced sideways or vertically. If, however, there are obstructions on the wall of the tank or elsewhere, different impellers will give one of two types of flow patterns: axial or radial. The marine-type propeller produces axial flow; the flow leaves the impeller in the direction of the axis of rotation, as illustrated in Fig. 21.8. It should be noted that there are vertical and lateral flow lines; liquid is moved up and down and horizontally, providing good top-to-bottom turnover, which is important for good mixing.

When flat paddles or turbines are rotated with obstruction in the liquid, the liquid moves from the turbines in a plane perpendicular to the axis of rotation. This is called radial motion, and any impeller which generates this type of flow is classed as a radial-flow impeller. The flow pattern is shown in Fig. 21.9. Here, as in the case of the propeller with baffles, there are vertical and lateral flow currents resulting in motion conducive to good mixing.

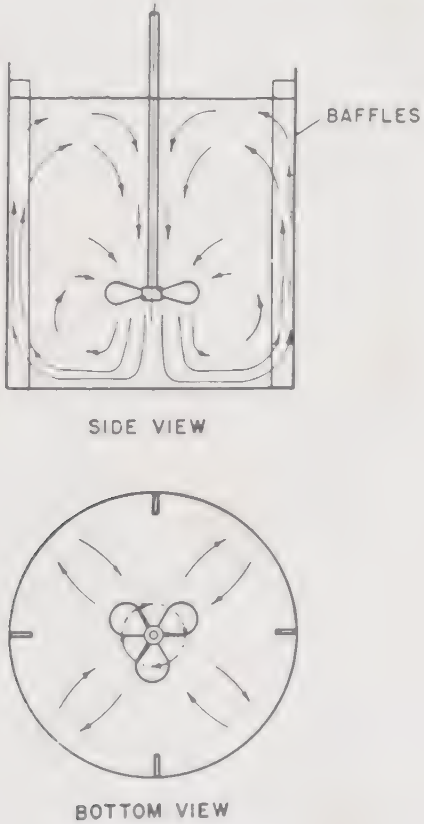
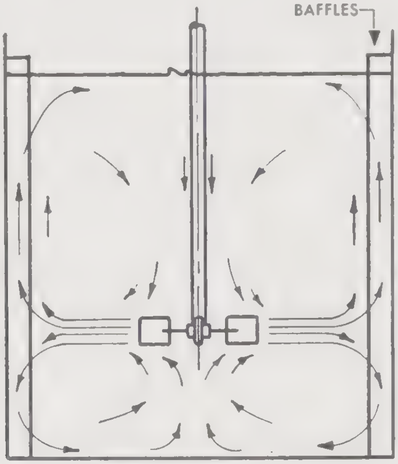
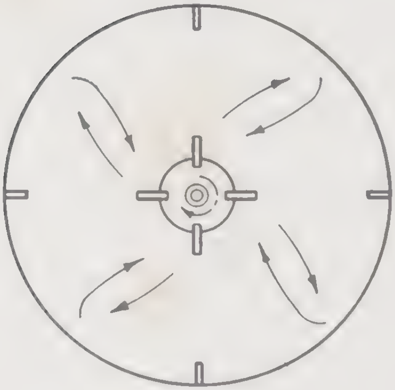


Fig. 21.8. Flow pattern for propeller with baffles; axial flow.

The liquid motion from the impeller therefore depends upon the shape of the impeller and also upon the obstructions present or the physical boundaries of the liquid. Ordinarily, the obstructions used to prevent rotary motion and swirl are baffles placed at or near the tank wall; these usually extend $\frac{1}{12}$ of the tank diameter from the wall, or they may extend vertically the full liquid depth or only a portion of the depth. If some rotary motion and swirl is desired at the surface of the liquid, baffles can be used in the lower part of the liquid, but are cut off below the surface. This will result in some swirl and vortex around the shaft—a condition sometimes desired in cases where solids are to be introduced into the liquid, for if the solids are hard to wet they can be poured into the vortex. Sometimes it is desirable to separate heavy objects at the bottom of a tank by cutting off baffles at the bottom, thus allowing for some rotary motion to be developed there.



SIDE VIEW



BOTTOM VIEW

Fig. 21.9. Flow pattern for turbines with baffles; radial flow pattern

Ordinarily, impeller shafts enter through the top surface of the liquid, centered, and baffles are used. However, propellers can be used to give axial flow, top-entering without baffles, or side-entering without baffles, in off-centered positions. Fig. 21.10 shows the off-centered position for a top-entering mixer (either portable or fixed), with the propeller turning counterclockwise as one looks down the shaft. In this case the shaft is to the left of the center line looking down the shaft, and the angle of the shaft is approximately 15 degrees from the vertical. The position is a very critical one and depends upon tank diameter, liquid depth, and height of impeller above the tank bottom. The proper location can be found readily by moving the shaft to various angles and to the proper side of the tank until all swirl and vortex disappear from the top of the liquid. The discharge of liquid from the propeller is axial in direction. Sometimes this position is referred to as equivalent to the use of baffles, since a propeller will give axial flow only when swirling motion is eliminated. Also, the power required by a propeller in the off-centered position is equal to that required when four baffles, each $^1/_{12}$ of the tank diameter, are used at the tank wall.

Side-entering propellers are used in large-diameter tanks (20 to 100 feet) for blending and other operations where large-diameter impellers are not required or would be inconvenient. The propeller is placed on a shaft entering through the side of the tank. Proper positioning is essential to avoid rotary and swirl motion. Baffles can be used to achieve proper lateral and vertical flow currents, but they can be dispensed with if the propeller

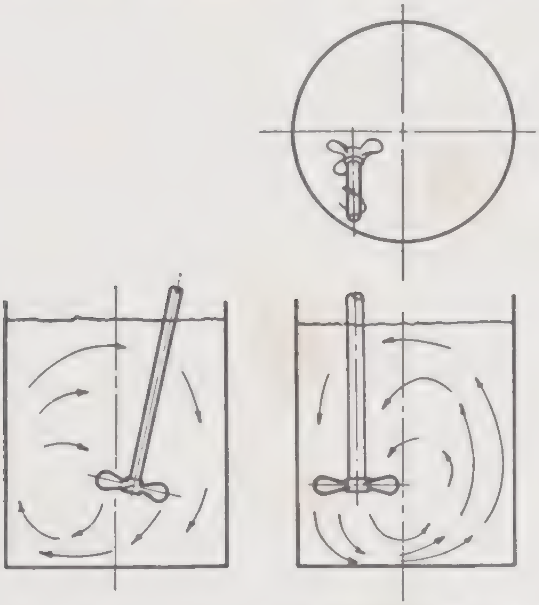


FIG. 21.10. Flow pattern for propeller in top-entering, off-center position (rotation counterclockwise looking at propeller along shaft).

shaft is placed in the proper off-centered position. Fig. 21.11 shows the side-entering position for a propeller rotating clockwise as one looks along the shaft toward the propeller. The axis of the shaft is displaced to the left of the tank diameter, usually from four to ten degrees. This position is a function of tank diameter and liquid depth and it is just as critical as the top-entering off-centered position. If a side-entering mixer is placed on the wrong side of the diameter, or if its direction of rotation is opposite to that required, there will be a swirling motion and a minimum of mixing for the energy expended.

Impellers are important items for mixing but they alone do not control flow motion. It should be emphasized that the configuration of the tank, the nature of the liquid, and the location of the impeller are just as important as tank fittings and impeller design in determining a flow pattern, and all these factors must be considered for proper mixing. Figs. 21.6 and 21.9 show the preferred use of tank fittings in mixing operations. The three common forms of mixing impellers, marine-type propellers, paddles, and various forms of turbines, will usually perform the work of impellers of any other shape within reasonable limits.

There are modifications of these principal types, but they are only for specific purposes. For example, a "weed-free" propeller has a blade design different from that of the ordinary marine-type propeller. The flat paddles are curved rather than straight, which allows them to start with less power in highly viscous liquids. Except for such considerations, there is little need to consider the many thousands of impeller designs that have been sug-

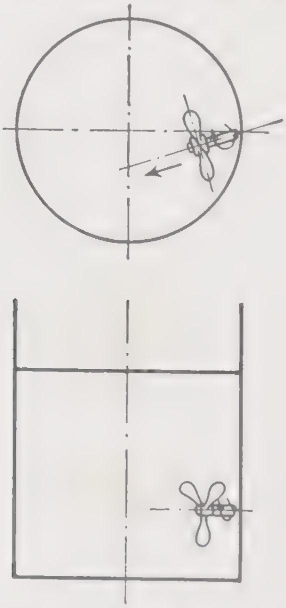


FIG. 21.11. Propeller in side-entering position (rotation clockwise looking at propeller along shaft).

gested for mixing. There are, however, shapes like a cage (or an egg beater), and a flat disk, rotating in its own plane, which are, of course, extreme types of radial-flow devices, and they have specific uses. Unless a particular flow pattern required by an operation cannot be obtained from one of the ordinary-type propellers, or turbines, it is not necessary to resort to improvised impeller design; all small-scale laboratory research and pilot-plant work should be done with commercial forms of impellers.

It has been known for many years that it is usually desirable to use mixers in such a way as to eliminate appreciable vortexing. The vortex prevents rapid mixing, since very little power can be applied, and it also precludes the use of reaction rate data for direct scale-up. Hence, if scale-up is to be achieved, vortices must be eliminated by the use of baffles (either close to or distant from the impeller), or by proper off-centering of propellers entering either from the side or top as illustrated in Figs. 21.10 and 21.11.

Performance Characteristics of Mixing Impellers. Power necessary to rotate mixing impellers and thereby cause flow and turbulence, the quantity and velocity of fluid discharged by these impellers, and the head developed by mixing impellers have been correlated for many shapes, fluids, and tank shapes and fittings. The power necessary to rotate an impeller is a function not only of its shape, size and speed, but of its position with reference to tank bottom, side and liquid level, and also to the physical properties of the fluid. There have been many publications relating to speed, power and fluid properties, but the most comprehensive coverage of such material has only recently been published[2]. Correlations are based on similitude principles. A wide range of types and sizes of mixing impellers has been studied and can be summarized by reference to Fig. 21.12 and Table 21.2.

Fig. 21.12 is typical for the operating characteristics of a flat-blade turbine mixing impeller, shown in Fig. 21.6, as manufactured by Mixing Equipment Company. Curve *ABCD* results for operation when baffles are placed at or near the tank wall, as illustrated in Fig. 21.8. Curve *ABE* results for operation when no baffles are present and swirl and vortex exist. The following general equations are applicable for these curves and relate power, P, speed of rotation, N, impeller diameter, D, liquid viscosity, μ, liquid density, ρ, and the gravity constant, g. For curve *AB*, viscous flow

$$P = \frac{K}{g}\,\mu N^2 D^3 \tag{1}$$

For curve *CD*, fully developed turbulent flow

$$P = \frac{K}{g}\,\rho N^3 D^5 \tag{2}$$

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[2] Rushton, J. H., Costich, E. W., and Everett, H. J., *Chem. Eng. Progress*, **46**, 395 467 (1950).

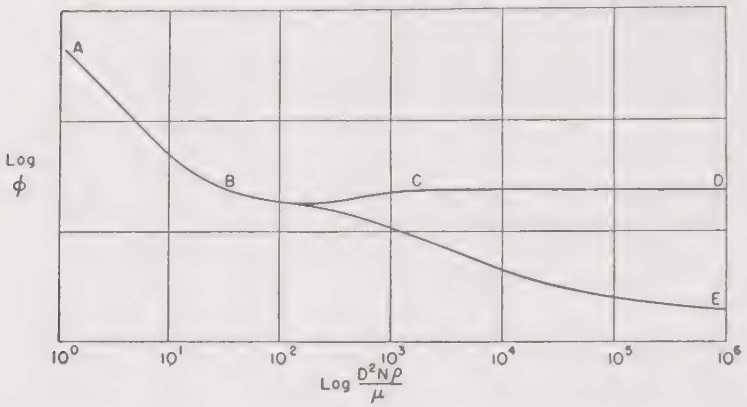

Fig. 21.12. Power characteristics of a mixing impeller.

Table 21.1. Values of K for Equations 1 and 2

Impeller with Four Baffles at Tank Wall, Each 10% Tank Diameter	Equation 1 Viscous Range	Equation 2 Turbulent Range
Propeller, square pitch, three blades	41.0	0.32
Propeller, pitch of two, three blades	43.5	1.00
Turbine, six flat blades	71.0	6.30
Turbine, six curved blades	70.0	4.80
Turbine, six arrowhead blades	71.0	4.00
Fan turbine, six blades	70.0	1.65
Flat paddle, two blades	36.5	1.70
Shrouded turbine, six curved blades	97.5	1.08
Shrouded turbine, with stator (no baffles)	172.5	1.12

No equation is recommended for curve BE, since the slope of the line is not constant and little practical use can be made of such an equation. K is a constant depending on the impeller shape, size, the number of baffles, and in fact all variables other than those shown in the equation. The value of K is determined from the ordinate of Fig. 21.12. For impellers rotating on the center line in a vertical cylindrical vessel with a flat bottom, a liquid depth equal to the tank diameter, impeller diameter one-third of tank diameter, and impeller one diameter above tank bottom, the values of K are given in Table 21.2 for different types of mixing impellers. The position described is a common one, widely used in industry. The values of K have been determined for a large range of sizes. For side-entering propellers properly positioned and for top-entering propellers without baffles but off-centered to prevent vortexing[2], the value of K is the same as for the baffled position and the values of Table 21.2 apply. Values of K for some other impeller positions and variables are also available[2].

Data are available for mixing operation involving heat transfer[3, 4], mass

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[3] Chilton, T. H., Drew, T. B., and Jebens, R. H., *Ind. Eng. Chem.*, **36**, 508 (1944).

[4] Cummings, G. H., and West, A. S., *Ind. Eng. Chem.*, **42**, 2303 (1950).

transfer[5, 6], and gas-liquid contacting[7, 8], wherein the foregoing principles and the elimination of vortexing allow them to be directly useful for scale-up. From these and more recent data, a general technique has been suggested for correlating mixing data from bench scale or pilot plant studies[9]. When mixing is accomplished with baffles or their equivalent so that no vortex is present and dynamic similarity can be achieved at various scales, the power characteristics of the impellers are as shown in Fig. 21.12. If an impeller such as a flat-blade turbine is used, the correlation between power, speed, size and the liquid density and viscosity is as shown in curve *AD*, Fig. 21.12. With such operating characteristics the flow pattern present in small-scale operation can be duplicated at larger scale with geometric and kinematic similarity, and the forces present at corresponding points can be made equal to those at the small scale, or larger if desired, by increasing the impeller speed without destroying kinematic similarity. This makes it possible to achieve not only dynamic similarity at a change of scale, but also equal flow velocities at a given point, such as at a reaction interface.

Marine-type propellers, especially when welded to the shaft and ground and polished so as to present no crevices, are much more desirable from the standpoint of sanitary design than the flat-blade turbine illustrated in Fig. 21.6, although there is no reason why the latter cannot be made sanitary in both design and construction with proper streamlining. Obviously, it is important that attention be given to the metals used in their construction, so as to avoid any possible contaminating influences, as described in Chapter 14.

Slow-Speed Mixing. Slow-speed agitators are built in a number of designs, most of which are variations of the ordinary paddle mixer. The simple paddle mixers, horizontal, single-arm or double-arm, vertical or gate types, all tend to swirl and stratify the contents of a tank, thus defeating the intermixing of liquids of different specific gravities. Slow-speed paddle agitators are used extensively in some food industries where the higher degree of agitation provided by high-speed mixers might prove undesirable due to incorporation of air or the possible churning of the

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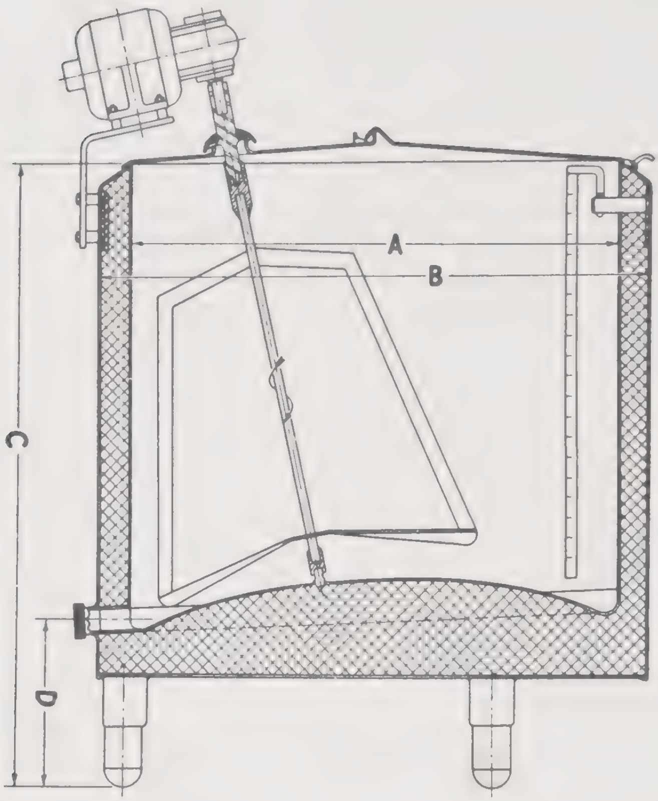
[5] Mack, E. M., and Marriner, R. E., *Chem. Eng. Progress*, **45**, 545 (1949).

[6] Mason, J. A., unpublished Chemical Engineering thesis, Illinois Institute of Technology, Chicago, Ill., June, 1950.

[7] Bartholmew, W. H., Karow, E. O., and Sfat, M. R., *Ind. Eng. Chem.*, **42**, 1827 (1950).

[8] Bartholmew, W. H., Karow, E. O., and Sfat, M. R., *Ind. Eng. Chem.*, **42**, 1810 (1950).

[9] Rushton, J. H., *Chem. Eng. Progress*, **47**, 485 (1951).



Courtesy Creamery Package Mfg. Co.

FIG. 21.13. Slow-speed agitator with wide sweep pitched to match the slope of pan bottom in stainless steel blending tank.

material. For example, it is usually desirable not to agitate raw milk too vigorously, and slow-speed blenders have been designed to perform gentle mixing (see Fig. 21.13).

The continuous mixing of two streams of low-viscosity liquids can be provided by bringing them together at the intake of a centrifugal pump and mixing them by the action of the impeller within the pump itself. The proper utilization of baffles will also provide for the mixing of liquids, as has already been demonstrated by the degrees of turbulence that can be created.

The homogenizer, which produces a uniformly divided dispersion of one liquid in another and thus provides fairly stable emulsions, is also an effective blender or mixer for liquids of low viscosity, such as milk.

Occasionally, air agitation is resorted to in the mixing of liquids, the air being introduced by a sparger pipe in the bottom of the tank and causing agitation as it passes upward through the liquids; or it can be introduced into the bottom of an air lift to produce internal circulation of the liquid as well as agitation. In this connection, it has recently been demonstrated that air agitation (or more accurately, the agitation provided by properly passing the headspace, or void space, through the center of a hermetically sealed metal can) expedites the thermal processing of the contents markedly, in contradistinction to that necessary when relying upon mixing of the contents by convection currents only. An increasing number of food processors are becoming cognizant of the advantages of mixing, or agitating, the can contents during heating and cooling. Consequently, there is a growing recognition that the type of agitation is one of the most important factors to be evaluated in any study of heat transfer.

Mixing Canned Products. There may be some question in the reader's mind as to the proper place to discuss the mixing of the contents of a can of food under thermal processing, as it is so intimately associated with the rates of heat transfer. Then, too, this type of processing has proved particularly advantageous when dealing with viscous semiliquid products. Such objections have validity, but in a chapter dealing with mixing, it is not possible to ignore the incidental benefits of the agitating effects of any mixing action, even though it may not contribute materially to "intimate contact of reacting substances." However, it does have "flavor-stimulating effects" that are of significant importance to any food engineer interested in capturing every possible processing advantage to enhance the flavor and acceptability of processed foods. While this discussion might be deferred to the chapter on heat exchanging, its importance as a processing adjunct seems to warrant its discussion at this time.

Careful studies made by the Research Department of the Continental Can Company[10] on the rate of heat penetration in cans agitated by a variety of methods indicated that the end-over-end principle of agitation at controlled speeds was superior to all other methods previously studied. Fig. 21.14 gives a diagrammatic presentation of the method of rotation and theoretical position and mobility of the contents of a can when it is rotated end-over-end at optimal speed namely, when the centrifugal force exerted on the can contents is equal to that of the force of gravity. This principle has been further studied by other investigators, and one report in particular seems to have confirmed and even extended the validity of the original findings as the result of some careful engineering studies[11].

The mixing of the contents of a can of food is affected by the motion of the can and the amount of headspace in the can. The proper method for measuring the "fill" of a can of food when the contents are at 150°F is shown in Fig. 21.15. This headspace of unfilled volume usually manifests itself as a bubble, which has a different motion from that of the liquid in

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[10] Clifcorn, L. E., Peterson, G. T., Boyd, J. M., and O'Neil, J. H., *Food Technol.*, 4, 450 (1950).

[11] Conley, W., Kaap, L., and Schuhmann, L., *Food Technol.*, 5, 457 (1951).

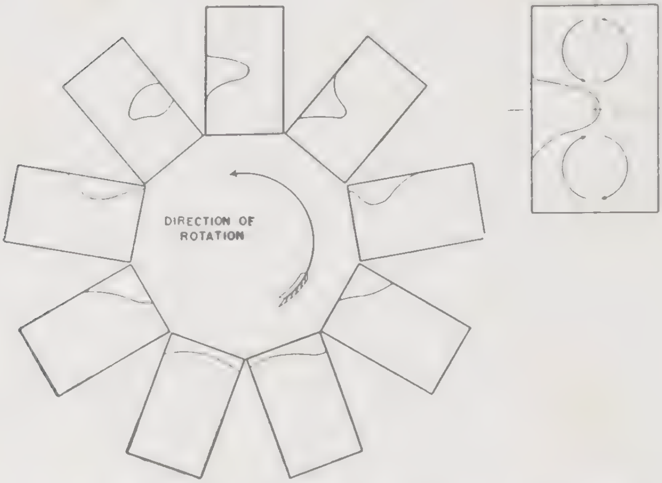


FIG. 21.14. Mobility produced at optimum rotation speed.

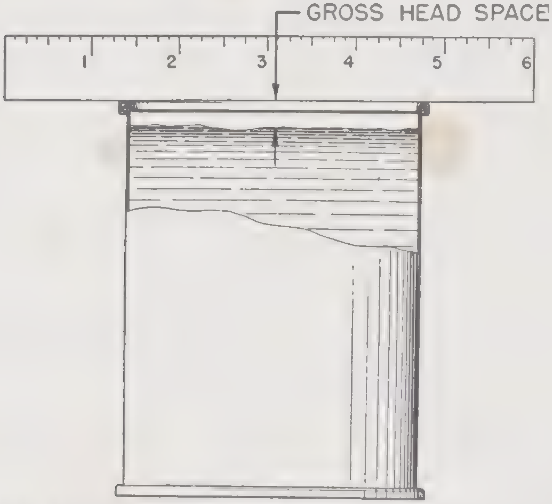


FIG. 21.15. Method of measuring gross headspace. Since gross headspace is determined by measuring from top of the double seam to the level of the product in the can, the net headspace is about ⅛ inch less than the gross headspace.

the can and thus acts as the mixing agent. It has been established that the rates of heating and cooling are influenced by (1) the distance of the can from the axis of rotation, (2) the rate of rotation, and (3) the amount of headspace. The optimum speed of rotation varies with the radius of rotation; as the speed of rotation increases beyond the optimum, the centrifugal forces created decrease the mobility of the can contents. Normally, a ⅜-inch gross headspace appears to be desirable for most products. There is a marked decrease in the efficiency of cooling when there is only ⅛-inch gross headspace, and an additional ⅛ inch greatly increases that efficiency.

There is relatively less effect on cooling rates as the headspace is increased beyond ¼ inch.

Other systems of thermal processing of canned foods take advantage of the headspace, plus any gases developed during cooking or sterilizing, to produce the bubble that aids in stirring the contents of the can. Rolling the filled cans will help to some degree in causing the bubble to mix the contents, particularly when any impact conditions are applied. However, the maximum advantage in mixing to be gained from use of the headspace in hermetically sealed cans seems to be offered by the end-over-end principle of rotation. This offers the advantages of (1) successful retorting of canned foods at a minimum of time, especially in large can sizes (see Fig. 21.16); (2) vast improvements in color, texture and vitamin retention of products that degrade with prolonged heat treatments; (3) modest canning operations for relatively unexploited heat-sensitive products (e.g., "sterile" versus pasteurized whole milk); and (4) wider ranges of processing time and temperature relationships for various products and in several can sizes, with their attendant economies in power generation and consumption. Among the more dramatic results which have been attained with this type of mixing during thermal processes is the observation that it has been found possible, for example, to reduce processing time to less than one-fifth its former value by raising the temperature only 20°F above that for a conventional "still" process.

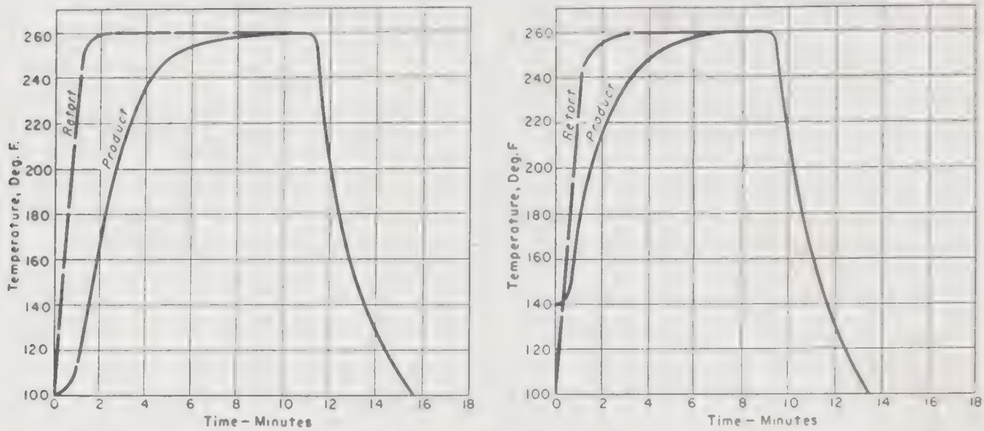
Mixing Liquids of Medium Viscosity

Liquids of syrupy or pasty consistency may be mixed by an agitator which operates between stationary fingers or baffles, as the high-speed type of propeller or turbine agitator is wholly unsuited for such materials. The type of agitator just described spreads out the material into a thin layer as the agitator passes the baffles, and the material is mixed by the drag following the agitator.

Many mixers of viscous liquids and pastes utilize scrapers to keep the product from the container walls, with paddle-type or screw-type agitators to impart a squeezing or rubbing action. Ribbon mixers, more commonly used as dough mixers, find limited application in the mixing of liquids of fairly high viscosity. This type of mixer, while built in a variety of patterns, consists essentially of a helical ribbon which rotates in one direction around a screw impeller or a second helical ribbon rotating in the opposite direction.

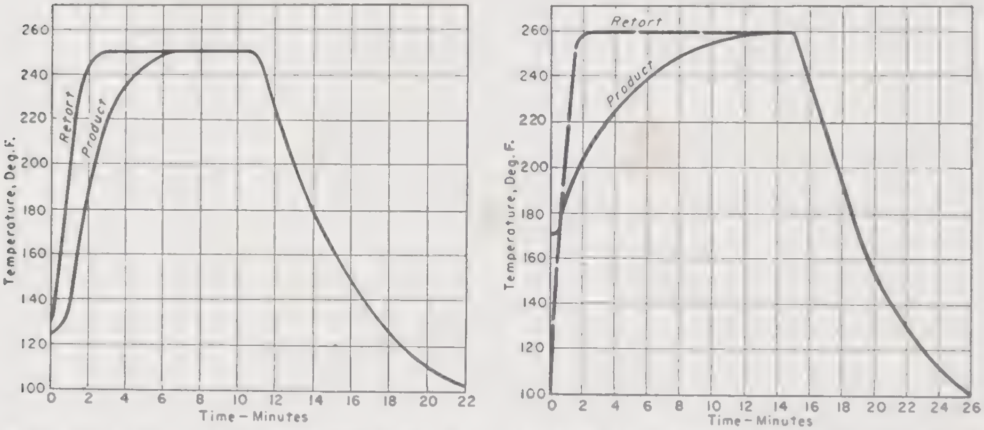
Mixing Liquids of High Viscosity

Kneaders are used where very heavy doughs are to be mixed. Generally the power requirements are very high (e.g., one horsepower to each five gallons). The agitator may be either single or twin slow-speed, and the shape



Alaska Peas, in No. 10 can, *F*o 14, processed at less than optimum speed to avoid product damage.

Whole-Kernel Corn in brine, No. 10 can, *F*o 16, processed at optimum speed.



Spaghetti and Meat in No. 10 can, *F*o 6.5, processed at optimum speed, with 1-min. venting.

Cream Style Corn, in No. 10 can, *F*o 20, at optimum speed. Viscosity was 11 sec at 180°F.

Courtesy "Food Engineeering"

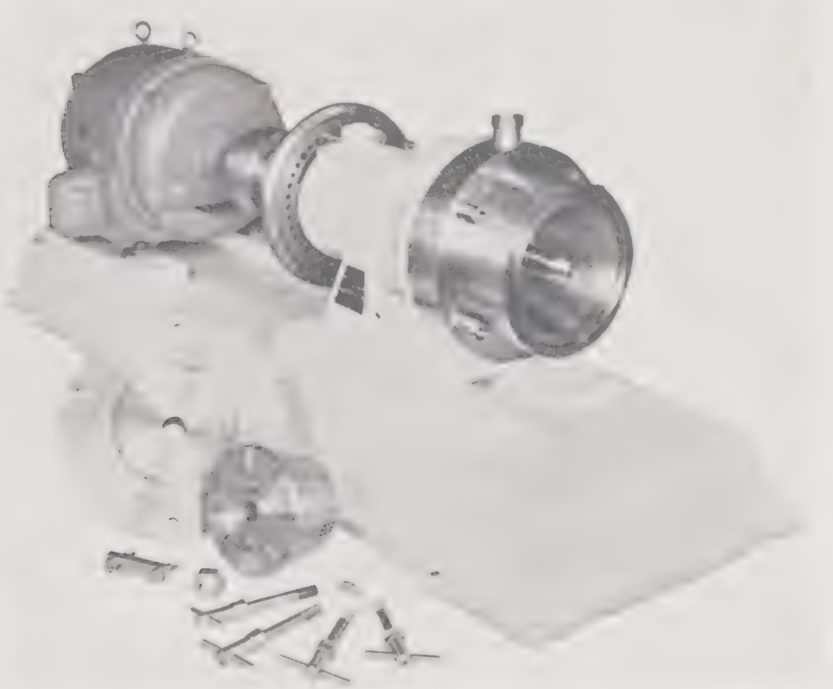
FIG. 21.16. Representative process charts of various products packed in No. 10 cans subjected to end-over end retorting. Note that the symbols *F*o and the numerals in each chart refer to the temperature above conventional still retorting processing temperature (e.g., *F*o 14, means 14°F higher than conventional still retorting).

used depends largely upon the product to be mixed. Any mixers used for liquids of high viscosity must be exceedingly powerful. Several of the mixers used for medium-viscosity liquids can be adapted to fairly heavy viscosity or plastic masses, providing the proper adjustments in construction and power are provided. Roll mixers also have some applications in mixing high-viscosity liquids.

Mixing Liquids with Solids

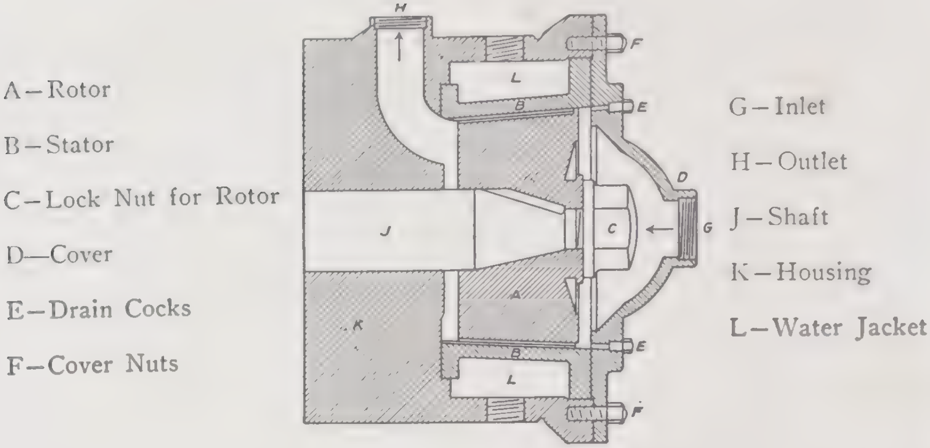
The mixing of liquids with solids in such proportions that the final mass is liquid rather than solid can be accomplished by the same techniques used for mixing liquids. The viscosity of the liquid phase is generally the determining factor in the choice of the mixing machine. However, in some mixes the presence of the solid phase, even in very small amounts, may increase the apparent viscosity of the mass; and although the material may be suspended in a liquid of low viscosity, the presence of the solid may produce such a thick paste or dough as to require the action of a kneading machine. Obviously, in such mixing problems, it is usually customary to start the mixing operation in a low-viscosity mixer of some kind and transfer the material to various other types of mixing equipment in progressive steps, the kneader representing the final machine for the addition of solid material.

The colloid mill is a specialized mill for making extremely fine suspensions of either solids or liquids in a liquid. This device corresponds to the ho-



Courtesy Chemicolloid Laboratories, Inc.

FIG. 21.17. Disassembled colloid mill, sanitary type, showing grooved conical rotor which mounts on shaft for rotating within the grooved conical stator, lock nut, wedge, cross bar with bolts, cover with sanitary threaded inlet and cover bolts. Note also sanitary threaded outlet at top of housing.



Courtesy Chemicolloid Laboratories

FIG. 21.18. Cross-sectional diagram of colloid mill.

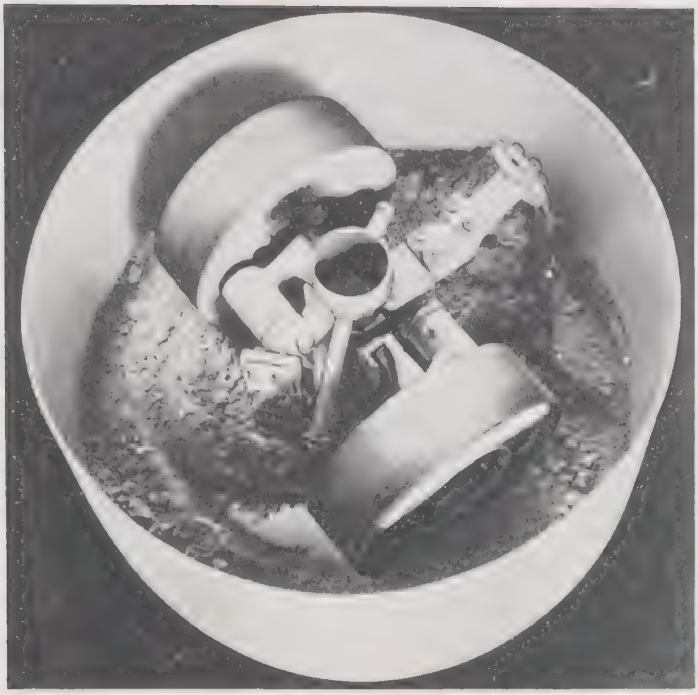
mogenizer for liquids, but is more versatile, since it is capable of preparing either emulsions (liquids-in-liquids) or suspensions (solids-in-liquids). The materials are mixed as they pass between a rapidly rotating solid rotor and its solid casing (see Figs. 21.17 and 21.18).

The ball mill can be used to obtain very thorough mixing of solids and liquids. Semicolloidal dispersions can be readily prepared, the mill acting simultaneously as a grinder and mixer.

Muller mixers are used most extensively in the candy field to disperse the sugar and the chocolate or cocoa liquor. There is probably no other mixing machine in the food industry which has so great an effect upon the quality of product as the conche machine does on the quality of chocolate. Conching blends the mixture of sugar, cocoa and butter into a practically homogeneous mixture of smooth consistency; each granule of sugar is coated with cocoa butter in such a manner that the greasiness of the product is eliminated and the storage properties enhanced. Melangeurs are also used extensively in the blending of chocolate products; they combine grinding and mixing operations. Both the conche and the melangeur were described in Chapter 18. Muller mixers are somewhat analogous to the roll mill used for the mixing of materials such as printing inks and paints in the chemical industries.

MIXING OF MATERIALS WITH SOLIDS

Most of the mixing operations involving solid food materials are those concerned with mixing two or more solid materials. To get intimate mixing, the solids must be finely ground. Mixing of solid powders is far simpler and less expensive than the mixing of either viscous liquids or pastes. The mixing of either a gas or a liquid with a solid is often required.



Courtesy National Engineering Co.

FIG. 21.19. Laboratory Muller mixer.

Mixing Gases with Solids

In food processing, the most common instances where the food engineer is concerned with the mixing of gases with solid food materials are those of the gas packing of foods such as milk powder, coffee, etc.

The gas packing of milk powder (particularly whole milk powder) normally presents a problem of maintaining a minimum oxygen content within the sealed package. In the spray-drying of whole milk, appreciable air is apparently occluded within the individual spherical particles of dried milk; this is not immediately removed or displaced in vacuum or gas-packing. The secret of successful packaging of whole milk powder involves the use of a commercially practicable procedure that will release this entrapped air and thus reduce the oxygen concentration to as low a level as possible. The usual quality standards for premium grade whole milk powder require that the oxygen content of the gases in the sealed container shall not exceed 3 per cent (calculated to atmospheric pressure) after at least one week from the time of gas-packing.[12] To meet such a standard, it is common practice to either vacuumize the powder or gas-pack it in sealed steel drums and so hold it before its final packaging, when it is again vacuumized and gas-packed[13].

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[12] Basis of calculation is milliliters of oxygen per 100 grams of powder. Limit is 3 ml/100 grams $\approx$ 13.5 ml lb can. Usual gas volume is 300 ml so oxygen should not exceed 4.5%, preferably 3%.

Packing in an inert gas has proven to be the most satisfactory method of packaging whole milk powder. Carbon dioxide has the advantage of being cheaper and containing less oxygen than bottled nitrogen. However, when whole milk powder or other products containing fats are packed in an atmosphere of carbon dioxide, a vacuum develops in the container. It is thus not possible to use 100 per cent carbon dioxide in cans larger than the one-pound size, due to panelling. Carbon dioxide is now rarely used, and most manufacturers of dried whole milk appear to consider nitrogen the more suitable gas to use, although one large manufacturer is reported to use a mixture of 20 per cent carbon dioxide and 80 per cent nitrogen.

Equipment for semiautomatic and automatic packaging of whole milk powder and other food solids has been developed and is used extensively. In the semiautomatic units, the gassing box is the pivot of the packaging operation. In this box are placed the trays of cans that have been filled [with the product.] The cans either have one or more vent holes in the cover, or the cover is only loosely fastened by a "clinching" operation. The entire gassing box containing the filled cans is then vacuumized, following which the vacuum is displaced with the inert gas. Some operators first vacuumize and displace with carbon dioxide and repeat by vacuumizing and displacing with nitrogen gas as a second step. A pressure of from one to three pounds gauge is developed with the nitrogen gas, following which the gassed cans are removed into the atmosphere for immediate sealling. The cans with vent holes are tipped with solder while those with clinched tops are sealed by the double-sealing operation of an automatic closing machine. In either case, the sealing is completed immediately to prevent the entrance of air into the filled containers. The present completely automatic packaging unit consists of a series of bell chambers arranged radially, their vacuumizing and gassing operations being controlled by a centrally located rotary valve. The entire unit is synchronized with the clincher and the closing machine.

A significant proportion of packaged coffee now sold in this country is pressure-packed. The packaging steps are similar to those outlined for dried whole milk above. Fuller detail will be found on page 330 of Volume 1.

It is possible to speculate that future packaging techniques of mixing gases and solids may follow those pursued in the fluidized bed practices in chemical engineering, where the solid is reduced to granules which are suspended in a slowly moving stream of gas, with no tendency for channeling and with excellent contact between solid and gas. This may well prove the next logical step in the packaging of whole milk powder, for example.

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[13] Refer to Schibsted patent and W. G. Hawley patent.

This principle is already being used in the materials handling of bulk quantities of wheat flour, for example (see Chapter 20).

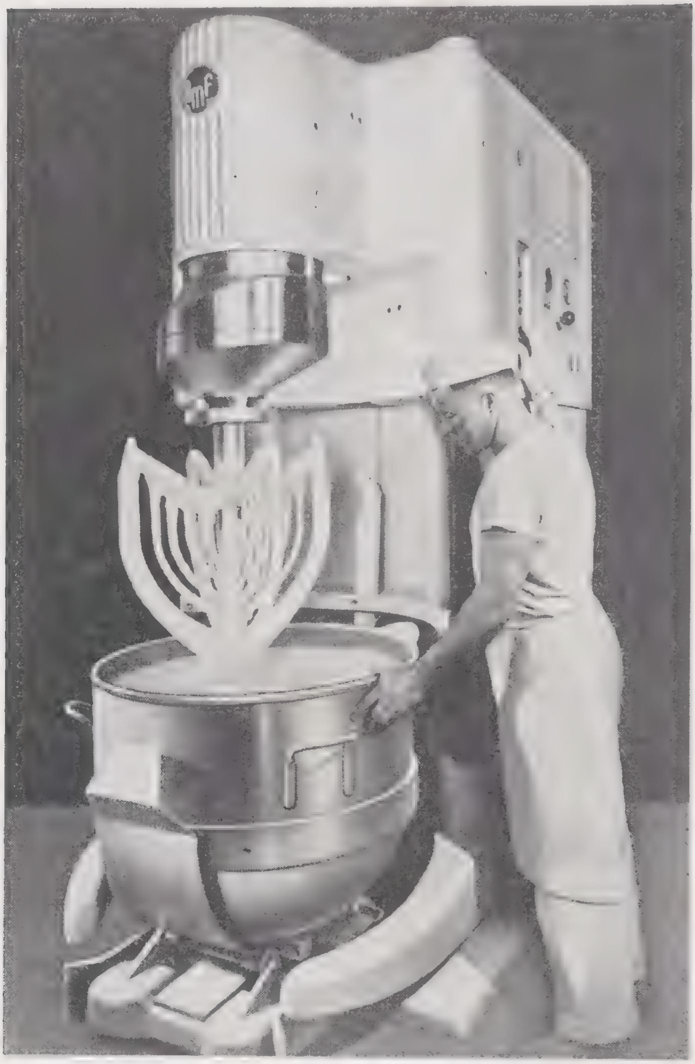
Mixing of Liquids with a Solid

In the preparation of some processed foods, it is sometimes necessary to add barely enough liquid to a solid mass to wet the solid. This requires an appreciable working of the mixture to distribute the liquid evenly through the mass. This can be done in a granulating machine or even in a kneading machine. If the solid material is granular and not reduced to a plastic or doughlike consistency, it can be mixed in a dry solids mixer. A melangeur may also be used in some cases.

Probably the most widely used mixer is the vertical mixer found in bakeries and in confectionery, mayonnaise, and various other types of food-processing plants. This type of machine is used for making cake batters, meringue, salad dressing, mayonnaise, and similar mixtures. It will mix almost any consistency from light foam batches to bread doughs. Variable speed control gives constant and accurate control at every mixing stage. An elevator fork which supports the bowl permits it to be raised and lowered. A bowl tilting truck or dolly upon which the bowl is mounted facilitates the handling of heavy batches as some bowls have capacities up to 340 quarts. The bowl is raised and lowered either by power or manually. There are a variety of beaters which may be used interchangeably in the mixer. The vertical mixer is usually designed to give beater action in two planes as well as to revolve on two axes, i.e., as it rotates on its own axis it also travels around the inner circumference of the bowl (see Fig. 21.20). Rubber-edged beaters eliminate the necessity for hand scraping down the sides and bottom of the bowl as the beater mixes. The rubbing action gives better creaming and the wiping action brings unmixed materials into the mass of the batch while keeping it in constant agitation. Interchangeable mixing bowls make it possible to keep the mixer in practically continuous operation.

Mixing of Solids with Solids

In dry mixing, where tumblers or ball mill type mixers are used, a certain degree of periodicity is often encountered. The optimum mixing time depends first upon the mixer design and second upon the mixing characteristics of the product. Dumping the material into the mixer, mixing and then discharging is not enough, especially when the ball mill type is used. The most logical explanation would appear to be that at times the mill acts as a classifier and at other times as a mixer. Tumblers usually do not present as frequent failures.



Courtesy American Machine & Foundry Corp.

FIG. 21.20. Vertical mixer of 340-quart capacity. Note that bowl is mounted on tilting truck which facilitates handling.

Tumblers are well known and are widely used for mixing solids. They are basically closed drums into which the solids are introduced through a quick-acting, dust-tight port in the wall of the drum. The drum rotates on a horizontal shaft mounted on the axis of the drum. There are various modifications of tumblers. For example, longitudinal bars on or close to the inside surface of the drum, or a polygonal rather than a cylindrical shape, prevent the solid material from slipping on the inside surface of the drum, and promote more rapid and effective mixing.

A technique related to the tumbling drum is the use of the ball or the rod mill for the simultaneous blending and grinding of two or more granular solid materials.

Paddle mixers are used in many solid-solid mixing operations. A rotating pan with stationary plows is sometimes used for blending dry materials. A fairly satisfactory continuous mixer for solids is a specially constructed screw conveyor.

The mixing of powders may be accomplished by various machines differently designed and named. There are the blenders, sifters and mixers, each achieving the intimate mixing of powders. Among the more common types are rotary screens, consisting of drums made of perforated metal or screening. The drums revolve slowly in a vertical plane. Running horizontally with the length of the drum and sometimes parallel to the axis are several baffle bars which carry the powder above the axis of the drum so that some agitation is accomplished as it falls. The powder is introduced into the batch type mixer when the drum is stationary through a sliding or hinged door on the circumference of the drum. In the continuous mixer, powder is supplied through the tubular opening which functions also as an axle for the revolving drum.

There is also the rotary dry-batch mixer which operates on the tumbling principle to achieve mixing of dry materials. There are many different types of horizontal mixers in which numerous blade styles are used, all based on the principle of moving the material where it can be discharged. There are varying capacities of both horizontal and rotary drum mixers up to 2 tons per batch.

A centrifugal dry mixer in which the material is mixed while passing through a rotor which is directly connected to a motor handles up to 250 pounds per minute. The rotor consists of two discs spaced about one inch apart and held together by round rod-type supports which act as impactors. Centrifugal force throws the material against the rods and inside walls of the housing, from which it drops by gravity to the discharge spout.

22. Heat Exchanging

I. Heating Applications

Basic Definitions

The transfer, or exchange, of energy as heat occurs in most engineering processes, and food engineering is no exception. The primary objective of all industrial food processing is the conservation or preservation of foods by means that will provide the ultimate consumer with optimum quality at minimum cost. The processing of foods usually involves some kind of heat treatment, which consequently is a vital unit operation in the conversion of raw materials into finished products. Whether the particular processing involves increase or decrease in temperature (which is merely a measurement of the intensity of heat), an exchange or transfer of heat is performed. Heat is actually the kinetic energy of molecular motion, and is perceived by being transferred from a body at a higher temperature to one at a lower temperature. *Heat* therefore may be defined as the energy transferred or exchanged mainly by means of a difference in temperature.

In engineering practice the unit of heat is the British thermal unit, or Btu, which is the quantity of heat required to raise (or lower) the temperature of one pound of water one degree Fahrenheit. However, the same quantity of heat, when transferred to the same weight of materials other than water, does not produce the same amount or degree of temperature change. To correct for this property of materials we apply a factor called *specific heat* which is really the ratio of the heat capacity of the material to that of water.

If the only effect of heat is a temperature change, the Btu required to accomplish such a change is computed as follows:

$$\text{lbs material} \times \text{specific heat} \times (T_2 - T_1)$$

where T_1 = initial temperature, °F
T_2 = final temperature, °F

The term *sensible heat* is applied to the heat which causes a change of temperature. At any temperature, a substance has a specific amount of energy tied up in the motion of its atoms and molecules. The heating of water flowing through the jacket of a heat-exchanging kettle as a cooling agent is an example of sensible heat (temperature change):

Rate of flow of water	8,350 lb/hr
Temperature in	65°F
Temperature out	75°F

Sensible heat change of water equals:

$$8{,}350 \times 1.0 \times (75 - 65) = 83{,}500 \text{ Btu/hr}$$

Latent heat is the energy involved in a change of state or phase, such as freezing (solidification), melting (fusion), vaporization, and condensation, with no accompanying change in temperature. To melt a solid we must add enough energy to give the molecules the freedom required by the liquid state, and to vaporize a liquid we must add enough heat to produce the freedom required by the vapor state. After the added heat has caused the change of state, it is called *latent*, since it is recovered when the change of state is reversed.

Latent heat change in a single-component system occurs at some fixed temperature, depending upon the substance and the pressure on the system. If an increase in volume accompanies a change of state, an increase in pressure will oppose the state of change, and vice versa. Thus, in the vaporization of water there is an increase in volume: therefore an increase in pressure will oppose this change by raising the boiling point. For example, water at 212°F and at 14.7 psi will continue boiling at that temperature, producing one pound of vapor for every 970.4 Btu of heat added; this value is the latent heat of vaporization of water, or, as it is sometimes called, the latent heat of steam. However, if the absolute pressure is increased from 14.7 psi (gage pressure of zero psi) to 24.7 psi (gage pressure of 10 psi), the boiling point of the water will rise to approximately 240°F, and 1 pound of water vapor will then require 952 Btu to be converted from liquid to vapor. Conversely, this 1 pound of steam at 240°F will condense to 240°F water at 10 psi gage, with the liberation of 952 Btu. If 1 pound of water is at 240°F and 10 psi gage and the pressure is reduced to zero psi gage (or absolute pressure of 14.7 psi), sufficient latent heat will be liberated to reduce the temperature to 212°F. Most substances contract upon freezing, and consequently an increase in pressure raises the freezing point. Some substances, like water, expand upon freezing and for them an increase in pressure lowers the freezing point.

Latent heat changes in a multicomponent system take place at a temperature that is fixed by the composition of the system. For example, ice will freeze from pure water at 32°F, from a 5 per cent sodium chloride solution at 27°F, and from a 15 per cent sodium chloride solution at 12°F.

The amount of heat released in the freezing of water at 32°F is 144 Btu/lb, but in a sodium chloride solution where the change of state occurs at 12°F, only 124 Btu/lb of water is yielded.

Occasionally, food engineers encounter *heat of reaction*. Normally when a chemical reaction occurs between two substances, the energy content in the products of the reaction will not be the same as the energy content of the reactants. The reason for this is that the energy tied up in a chemical bond depends upon the atoms which are joined. Since a chemical reaction is a rearrangement of atoms, a change in energy content usually accompanies a chemical reaction. We are often confronted with the heat liberated by exothermic reactions, but seldom with the heat absorbed, which occurs in endothermic reactions. Most chemical reactions do not proceed at fixed temperatures, because they produce heat, which further increases the rate of the reaction; hence some means of absorbing the unwanted heat from exothermic reactions is necessary in order to maintain the optimum temperature for the reaction.

Also, food engineers are sometimes concerned with *mechanical heat*. In an operation in which agitation and heat transfer occur simultaneously, the heat equivalent of the mechanical power input must be taken into account when estimating the heat load, particularly when processing viscous materials. Nearly all the power input is consumed in overcoming the friction resistance of the product and of the mechanical parts of the processing equipment. We shall discuss heat loads in fuller detail in subsequent pages of this chapter.

When two bodies of matter at different temperatures are in contact with each other, heat is transferred or exchanged directly from one to the other by conduction. On the other hand, if they are not in direct contact, heat may still be transferred from one to the other by convection or by radiation. These constitute the three known methods of heat transmission and may be defined as follows:

(1) *Conduction* is the transfer of heat from one part of a body of matter to another part of the same body, or between two different bodies in physical contact, without significant displacement of the particles of the body or bodies.

(2) *Convection* is the transfer of heat from one point to another in a fluid, or between a fluid and a solid or another fluid, by the mixing of the fluids involved. If the changes in temperature create differences in density and thereby impart motion to the fluid, the operation is called *natural* convection. On the other hand, if the motion of the fluid is produced or enhanced by mechanical means, the operation is referred to as *forced* convention.

(3) *Radiation* is the transfer of heat by radiant energy illustrated by the warmth from the rays of the sun, for example, which emits electromagnetic

waves that travel through space to furnish both heat and light. Electromagnetic waves emanate from all bodies in all directions at all temperatures. These waves are forms of energy, and when they impinge on a body, some are reflected, some are transmitted and some are absorbed. The absorbed waves may be converted into high-grade forms of energy, as in photochemical changes. These are exciting considerable interest and speculation concerning the possibility that radiation absorption may induce biological reactions in foods without appreciable changes in temperature, and have given rise to the so-called "cold sterilization" of foods. More commonly, however, electromagnetic waves are converted into heat.

In most cases, the actual transfer of heat is produced by more than one of these methods of transfer. In all cases, however, the total rate of heat transfer may be expressed in terms of a driving force which is a decrease in temperature:

$$\begin{aligned}\frac{dQ}{dt} &= \frac{\text{Driving force}}{\text{Resistance}} \\ &= \frac{T_1 - T_2}{1/UA} = UA(T_1 - T_2)\end{aligned} \tag{1}$$

where $\frac{dQ}{dt}$ = rate of heat transfer (as in Btu/hr) in the direction from point 1 to point 2,

t = time (as in hr),

T_1 = temperature at point 1 (as in °F),

T_2 = temperature at point 2 (as in °F),

U = average over-all coefficient of heat transfer [as in Btu/(hr) (°F) (sq ft),

A = area of surface through which heat is transferred, or cross sectional area of material through which heat is being conducted (as in sq ft)].

There is also a growing interest in certain types of radiant energy as the sources of heat utilized in the processing of certain foods. There are a number of applications in the food industry to which so-called high-frequency (electronic or radio frequency) heating can be applied. There are two basic methods: induction heating and dielectric heating. The latter is of greater importance from the point of view of possible application to the food industry. Radar heating is a modification of dielectric heating. However, it is not the purpose of this chapter to discuss such methods of heating, as they have not yet acquired any significant acceptance in commercial practice. In fact, we shall devote our attention primarily to the more conventional methods of heat exchanging employed in the processing of foods, with the greater emphasis upon the transfer of heat by conduction and convection. There are, in fact, few cases in the food-processing industries in which these two methods of heat transfer do not apply. Some methods rely mainly on conduction, others on convection, the difference lying in the proportion of each method used rather in the method itself.

Heat Energy Transmission

Of the various known methods whereby heat may be transferred from one system to another, the one most commonly used in the food-processing industries is that in which the heat is generated in an outside heater and transferred to the absorbing unit in a stream of materials. The disadvantages of material loss in the system, heat wasted in transit, and the additional expense of the generating heater are definitely overbalanced by the important advantage of the better temperature control afforded by this method. Water vapor, or heated water (condensed steam) are the most widely used heat-transfer media. Both are cheap, easily available and readily replaceable in the event of leakage or accidental loss, are nonflammable, nontoxic, clean and easily handled.

The usual modern procedure in the use of water vapor as a heat-transfer medium is to produce the vapor at elevated temperatures, utilize this high-pressure steam for the generation of mechanical energy in steam turbines, and use the exhaust of low-pressure steam as a source of heat energy for food processing whenever possible. This exhaust or "process" steam, is inexpensive as a heat source and is used when the temperatures required can be obtained by condensing this steam. To a limited extent, flue gas direct from the burner, air, or an inert gas heated from some external source are used as heat-transfer media.

Heat is transferred to the liquid heat-transfer media in standard or special designs of the ordinary *steam boiler plant*. If it is necessary to transfer heat to gas, this can be accomplished in either recuperative or regenerative heat exchangers. In the *recuperative exchanger*, the gas medium is heated by being conducted through or around thin-walled tubes, the other sides of which are heated by the combustion product of a fuel. In the *regenerative heater*, the gas medium is heated by being passed over brickwork or broken stone which has been previously heated by passing hot combustion gas through the mass.

In cases where steam is condensed in the unit to be heated, difference in pressure between the inlet and outlet is more than adequate to assure rapid movement of fresh steam to the heat-absorbing surface. Condensate traps are arranged to discharge condensate to the atmosphere, or condensate pumps are used to return condensed steam to the boiler, to prevent the heat received from being flooded with liquid.

Heat may be transferred from one of the several media to the processing mass by either *direct heating* or *indirect heating*. In direct heating, the steam, vapor, liquid or gas is brought into direct contact with the food mass—a practice generally avoided because of the many opportunities for contamination and dilution. However, it should be remembered that the heat transfer in such an exchange is at a maximum, both in efficiency and speed of transfer, which makes this an efficient method when circumstances permit its use. In this type of heat transfer, the heat generated in a body is completely separated from the food mass and is then transferred directly into the mass itself. Indirect heat is conveyed to the receiving system through a wall which separates the heating medium from the heat-absorbing system. This method of transferring heat to the food mass is preferred, in spite of lower efficiencies and higher equipment costs. However, in the transfer of heat from a liquid or gaseous heating medium to an absorbing system, the heat must pass through a layer or film on either side of the separating wall, as well as through the wall itself. In order to obtain rapid heat transfer without inordinately large temperature differences between the two sides of the wall, either large surfaces must be exposed to the heat transfer, or mechanical or other means must be employed to reduce the thickness of the films, thereby increasing the flow of heat through them.

Film thicknesses are reduced by rapid flow of fluid past heat-transfer surfaces. This flow may be stimulated by forced circulation through heat exchangers, or by adequate mechanical agitation within the processing vessel or heat-absorbing food mass. Corrosion-resistant metal that is nontoxic, nonabsorbent and inert to food materials should be used for walls whenever possible, to avoid deleterious quality effects in the food mass itself. Incidentally, these metals are not always as good conductors of heat as are some of the more common metals, such as copper. Therefore, the food engineer will have to decide when heat-transfer coefficients will take precedence over product solubilities or other contaminating possibilities of the metals to be used for heat-transfer surfaces. Then too, he will occasionally encounter prejudices of operators that have to be overcome objectively. However, *the food engineer should never forget that heat-transfer surfaces are also food-processing contact surfaces*. Not only has metallic contamination to be prevented, but also the possibility of adverse electrolytic or catalytic actions.

Whenever possible, a food-processing kettle should be so constructed that its outside walls become the heat-transfer surface. The heat-exchanging medium is held against the vessel surfaces by hollow shells or *jackets* surrounding various portions of the processing vessels. These may be made in a number of patterns to produce better heat distribution or exchange, prevent hot spots, withstand proper pressures, develop better circulation and higher transfer rates on the heating side. Heat-transfer surfaces are also frequently constructed in the form of either vertical or horizontal *coils* fitting inside the processing vessels, submerged in any liquid to be heated or cooled; both stationary coils and rotating helical coils depend upon the utility of the processing vessel itself.

A third type of heat-exchanging apparatus which can be used for transferring heat to, or subtracting heat from, a liquid held in a vessel is that often used in evaporators. These tubular sections commonly called *steam chests* (because they were used first to heat and only more recently to cool) are either horizontal, with steam (or the cooling medium) inside the tubes and the liquid food material outside; or vertical, with the steam (or cooling medium) surrounding the tubes and the liquor to be heated (or cooled) inside the tubes. While it is usually axiomatic that any heat-transmitting apparatus can also be used for cooling purposes, the basis requirements involved in the processing of the food mass itself must be carefully considered and evaluated. Modifications of design are often necessary in the interests of time factors, which are fully as important as the temperature factors in the processing of many foods. In fact, it is not possible to conceive of any processing method where the factor of time does not have to be adjusted with reference to the temperatures involved to gain a desired result.

HEATING BY CONDUCTION

We have previously stated that "conduction is the transfer of heat from one part of a body of matter to another part of the same body, or between two different bodies in physical contact, without significant displacement of the particles of the body or bodies in either case." In the simple case of the steady flow of heat through a homogeneous substance between two parallel plane surfaces of equal area maintained at different temperatures, the rate of heat transfer is given by the equation:

$$\frac{dQ}{dt} = \frac{k(T_1 - T_2)A}{d} \tag{2}$$

where $\frac{dQ}{dt}$ = rate of heat transfer in Btu/hr,

T_1 and T_2 = the surface temperatures,

A = area of the suface,

d = thickness of the substance,

k = thermal conductivity of the substance in Btu/(hr)(sq ft)(°F/ft).

Obviously, most problems in heat transfer involved in the processing of food products will not yield to such resolution, as foods are not homogeneous in the sense that metals are; furthermore they introduce other factors not yet discussed. However, equation (2), which is but another form of equation (1), does help to define the *thermal conductivity* of a substance. It is measured by the Btu transmitted per hour per square foot of area, per inch (or foot) thickness per degree difference in temperature on the two sides of the wall exposed to the heating medium.

In applying the formula given above for the rate of heat transfer to any problems in which we ignore the film resistance, we will find that heat transfer is increased by (a) greater k values, (b) greater temperature differences, and (c) greater surface areas, while it is decreased by greater thicknesses of the heat transfer wall. The usual problem in heat transfer gives a quantity of heat to be transferred per unit of time under given conditions of temperature. However, it should be pointed out that in computing any actual heat-transfer problems involving gases or liquids in contact with the heat-transfer surface, the over-all conductivity of the surface wall is greatly affected by the conductivity of the surface film of (1) the heating fluids and (2) the material being heated; hence the conductivity of the metal wall is usually of less importance than the conductivity of the surface films.

The practical significance of these factors can be dramatically demonstrated by the fact that, in a thin-walled apparatus such as a pasteurizer, the actual heat transfer of a stainless steel vat is almost equal to that of a tinned copper vat, even though the conductivity of copper is from 9 to 10 times that of stainless steels. The reason is that the resistance of the slow-moving film of milk and water in contact with the surface causes a low conductivity, which is a greater factor than the conductivity of the metal in the overall heat transfer of the apparatus. We will show later in this chapter how this fact has been resolved in favor of continuous process equipment through elements of design, construction and operation.

It is often necessary to compute the conductivity of a metal wall made up of more than one metallic element. In such cases, the following formula can be applied:

$$\frac{dQ}{dt} = k_0 \times A \times (T_1 - T_2) \tag{3}$$

where $\frac{dQ}{dt}$ = Btu transmitted per hour

$$k_0 = \frac{1}{\frac{d_1}{k_1} + \frac{d_2}{k_2} + \frac{d_3}{k_3} + \cdots + \frac{d_n}{k_n}}$$

where A = heat transfer area in sq ft,

$T_1 - T_2$ = temperature differences in °F,

$d_1, d_2, d_3 \cdots d_r$ = thicknesses of successive layers in either inches or feet, depending upon units of k values,

$k_1, k_2, k_3 \cdots k_n$ = thermal conductivity of successive layers,

k_0 = over-all conductivity in Btu/(hr)(sq ft)(°Ft).

Referring to the pasteurizer apparatus mentioned above, the conductivity of its metal walls can be greatly increased if the milk and water films are moved rapidly over the surface. Viscous products will not permit rapid cooling, as viscosity adds another resistance factor to conductivity. For that reason, milk and similar products can be conveniently handled and continuously processed in plate pasteurizers which employ fast-moving films of both water and milk. On the other hand, heavy cream, ice-cream mix and similar viscous products are not so readily handled and consequently are commonly batch processed in vats. Modern apparatus is designed to give as much film movement as possible, in order to secure rapid heating or cooling which have a definite effect on quality retention.

When a liquid (or gas) is in contact with a solid wall, there is an adhering relatively stationary film or fluid on the surface of the solid; this becomes thinner as the velocity of the liquid parallel to the solid increases, and it breaks away from the solid wall only at very high liquid velocities, if at all. Heat is transmitted only by conduction through this film, although as soon as the heat has penetrated the film, the hot particles are carried away mechanically by the momentum of the main body of the fluid. Most liquids and gases are very poor conductors of heat, which means that these liquid films, if moving slowly, provide proportionately greater resistance to heat transfer.

Since the resistance to conductivity is enhanced by film thickness, it obviously is best reduced by any treatment which reduces the thickness of the film. The actual calculation of heat transfer through films is very involved, and the most accurate and dependable results are obtained by resort to film transfer coefficients which have been determined experimentally for different conditions.[1] It should be stated, however, that the factors causing high film resistance to heat transfer are (1) low velocity of fluids, (2) greater viscosity of fluids, (3) low conductivity of the fluids, and (4) lack of turbulence in fluid films.

The following general equation expresses the method of heat flow from a fluid, through one layer of heat-transfer material to another fluid.

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[1] The reader is referred to "Unit Operations" by Brown and Associates (John Wiley & Sons, 1950).

$$\frac{dQ}{dt} = k_0 \times A \times (T_1 - T_2) \tag{4}$$

where $\frac{dQ}{dt}$ = Btu transmitted per hour

$$k_0 = \frac{1}{\frac{1}{h_1} + \frac{d_1}{k_1} + \frac{1}{h_2}}$$

where A = heat-transfer area in ft,
T_1 = temperature of hot fluid in °F,
T_2 = temperature of cold fluid in °F,
h_1 = film coefficient of hot fluid in Btu/(hr)(sq ft)(°F),
h_2 = film coefficient of cold fluid in Btu/(hr)(sq ft)(°F),
d_1 = material thickness in inches or feet, depending on units of k_1,
k_1 = thermal conductivity values of material.

For turbulent flow of water inside smooth pipes, the film coefficient[2] is given by the following:

$$h = \frac{138}{D^{0.2}}\left(1 + \frac{50}{r}\right)\left(\frac{v}{\mu}\right)^{0.8} \tag{5}$$

where h = film coefficient in Btu/(hr)(sq ft)(°F) between pipe and fluid,
D = inside diameter of pipe in inches,
r = ratio of length of pipe to diameter,
v = average water velocity in ft/sec.,
μ = viscosity of water at mean temperature in centipoises.

Computing Heat Transfer in Heat Exchangers

If we were concerned only with heat transfer or heat exchange and could ignore time factors and their effects, we would need only to be concerned with their thermal capacity (mass × specific heat) of the products being processed, and with temperature change. For, if there were no outside loss or gain of heat, the amount of heat that would flow to or from either of the bodies could be determined by the formula:

$$\text{mass} \times \text{specific heat} \times (T_2 - T_1)$$

The final *stable* equilibrium temperature (T_2) would be:

$$C_a \times (T_2 - T_a) = C_b \times (T_b - T_2)$$

or,
$$T_2 = \frac{C_aT_a + C_bT_b}{C_a + C_b}$$

where C_a and C_b = thermal capacity of bodies a and b,
T_a and T_b = initial temperatures of bodies a and b.

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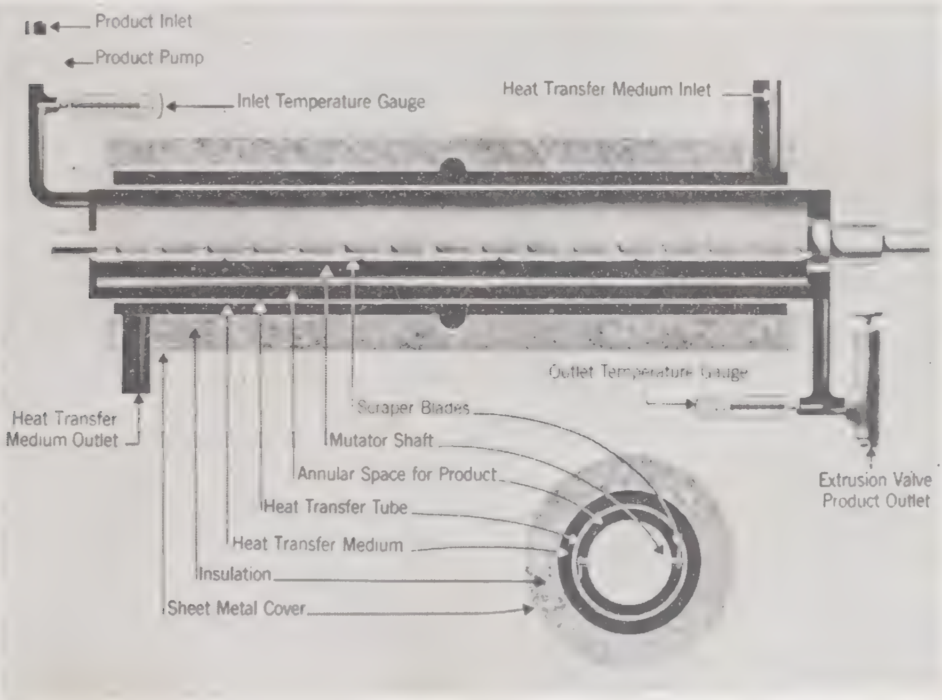
[2] McAdams & Frost, Mar. '24 according to ASRE Data Book '32–'33.

However, during heat flow the temperature difference of the bodies changes with time, and consequently the rate of flow of heat does likewise. This causes an *unsteady state* of thermal equilibrium.

Since much of the heat-processing of many liquid foods involves changing or maintaining temperatures under controlled conditions, heat exchangers, such as heaters or coolers, are of major importance to food processors. It is true that some practical limitations arise from the properties of certain liquid foods and that these greatly affect the capacity and efficiency of heat-exchange equipment. For example, the degree of agitation of milk must be kept within certain limits, even though it is known that greater agitation would cause more rapid heat exchange. Again, there must not be too great a difference between the temperature of the milk products and that of the heating medium; otherwise, "burning on" of milk solids, for example, may occur.

However, quite aside from these practical considerations and limitations, it is important to be able to know temperature conditions at certain times and locations. We are interested, therefore, in a steady state that can only be produced by supplying heat from the outside to one body and removing it from the other, in such a manner that the temperature at any given point



Courtesy The Girdler Corp.

FIG. 22.1. Votator heat exchanger. This compact, closed system heat transfer mechanism represents an effective and practical application of basic heat-exchange theory.

in the system will not change with time, but only with position or distance, such as through a heat transfer wall or along the wall. Such are the conditions that must be established in the operation of heat exchangers.

Fig. 22.1 shows a schematic drawing of a Votator heat exchanger that has wide application in the unit operations of food engineering and is used extensively in the continuous cooking, cooling, pasteurization, sterilization, crystallization, emulsification, aeration, mixing, caramelization and extrusion of various food products. It will be apparent that the temperatures will vary with the distance lengthwise; that with constant operating conditions the temperature at any point will be constant; and, therefore, that the temperature difference between any two points perpendicular to the axis of the tube will be constant. At any point, the rate of heat transfer between two points perpendicular to the axis of the tube will be directly proportional to (1) the difference in temperature between the two points, and (2) the resistance offered by the area available for the transfer of heat and by the intervening materials (including heat-transfer medium, the metal wall of the heat transfer tube, and the food material deposited thereon in the annular space for the product being heated or cooled).

Referring now to equation (1), we will recall that the basic concept of heat flow was represented as follows:

$$\frac{dQ}{dt} = \frac{\text{Driving force}}{\text{Resistance}}$$

$$\text{Flow} = \frac{\text{Driving force}}{\text{Resistance to flow}}$$

where flow = Btu/hr
driving force = Temperature difference in °F
resistance to flow = (°F) (hr)/Btu

This equation can be developed into a useful form for determining heat transfer in a heat exchanger such as that shown above. Resistance to flow is the reciprocal of conductance (not to be confused with conductivity), and the equation becomes:

$$\text{Flow} = \text{Driving force} \times \text{Conductance}$$

where conductance = Btu/(hr) (°F). Since this is for the total area involved,

$$\text{Conductance} = U \times A$$

where U = over-all coefficient of heat transfer in Btu/(hr) (sq ft) (°F).
A = area in sq ft.

Substituting this in the previous equation and changing nomenclature for flow and driving force we obtain:

$$Q = \Delta T \times U \times A \tag{6}$$

where Q = total (rate of) heat flow in Btu/hr,
ΔT = mean effective temperature difference between the hot and cold side in °F,
U = over-all coefficient of heat transfer in Btu (hr) (sq ft) (°F),
A = surface area available to heat transfer in sq ft.

In equation (6), note that an increase of U, with ΔT constant, will reduce the area required and therefore the time of processing.

The original flow equation (1) applies to any point in a heat exchanger; however, the temperature difference between the hot and cold sides is not constant, but varies throughout the length of the heat exchanger. Note that the term for driving force was changed to ΔT, the mean effective temperature difference, so that it would apply to the entire length of the heat exchanger. The variation of temperature is usually not uniform with respect to the distance, but in some cases the arithmetic mean temperature difference is sufficiently accurate. Usually the mean effective temperature difference is taken as the logarithmic mean of the terminal temperature differences when the flows of material through this type of heat exchanger are parallel, countercurrent or mixed (such as in the heating of a liquid by condensing steam).

The arithmetic mean may be computed by:

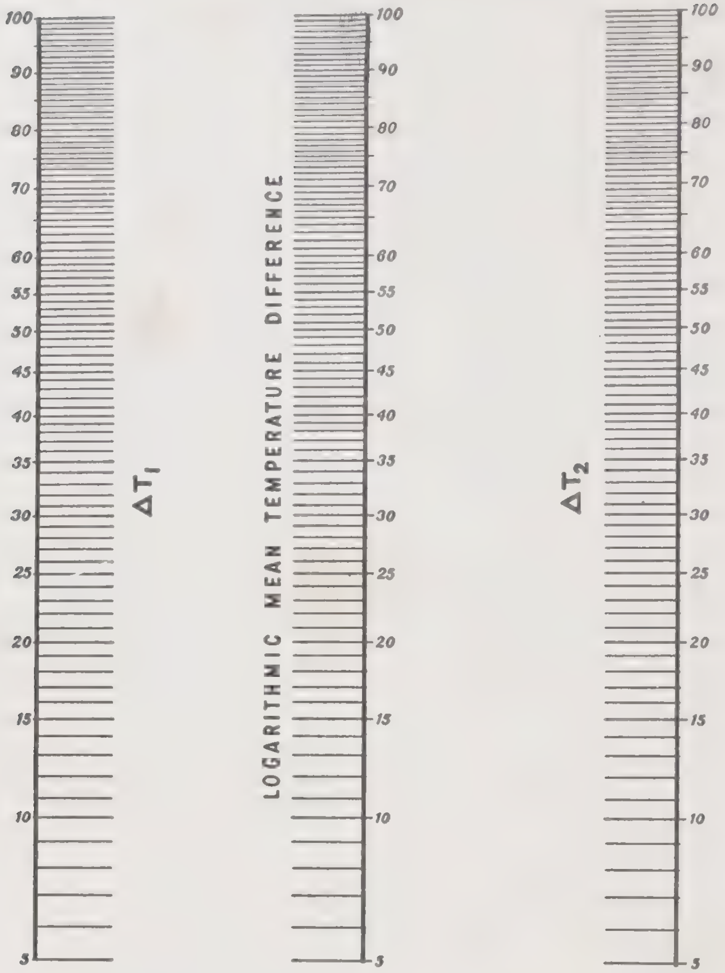
$$\Delta T_A = \frac{\Delta T_1 + \Delta T_2}{2} \tag{7}$$

where ΔT_A = arithmetic mean temperature difference,
ΔT_1 = greater temperature difference between hot and cold side at same end of heat exchanger,
ΔT_2 = lesser difference at other end of heat exchanger.

When the ratio of $\Delta T_1 : \Delta T_2$ is greater than 2.0, the error becomes appreciable (over 4 per cent) and the logarithmic mean temperature difference (LMTD) must be used; this is computed as follows:

$$\Delta T_L = \text{LMTD} = \frac{\Delta T_1 - \Delta T_2}{2.3 \log_{10} \dfrac{\Delta T_1}{\Delta T_2}} \tag{8}$$

For the Votator type of heat exchanger, this is the formula usually used, and a convenient chart prepared by the Girdler Corporation will be found in Fig. 22.2. LMTD is based on the existence of certain ideal conditions,



NOTE:

If $\triangle T_1$ and $\triangle T_2$ are not within the range of the chart, a multiplying factor may be used as illustrated by the following example:

$\triangle T_1$ (Actual) = 200 $\triangle T_2$ (Actual) = 20
Multiply $\triangle T$'s by ½
$\triangle T_1' = 100$ $\triangle T_2' = 10$
M.T.D. (From Chart) = 39.5
M.T.D. (Actual) = 2×39.5 = 79.0

Courtesy The Girdler Corp.

FIG. 22.2. Logarithmic mean temperature difference chart.

namely, that

(1) there is no change in state, such as by crystallization;
(2) the flow rates remain constant;
(3) the specific heats remain constant throughout the length of the heat exchanger;
(4) the over-all heat transfer coefficient, U, remains constant throughout the length of the heat exchanger.

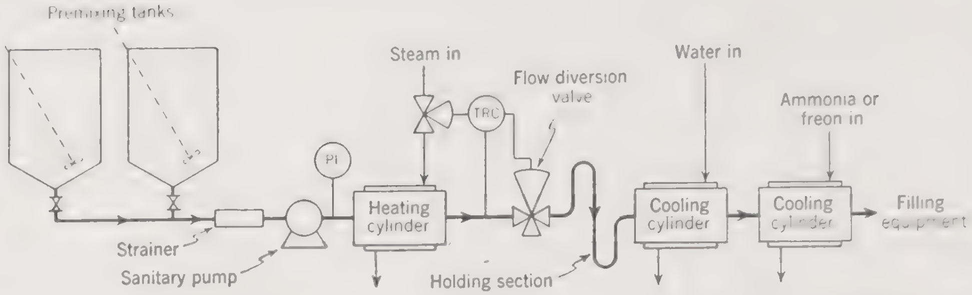
From the foregoing discussions of the various factors involved in the transfer of heat by conduction, the following practices for efficient heat exchange appear to be justified:

(1) use of rapidly moving fluid films on both sides of the heat-transfer surface;
(2) thorough and complete mixing of these fluid films with the body of the fluids (which then becomes heating by forced convection);
(3) use of the counterflow principle;
(4) use of as great a temperature difference as is consistent with accurate temperature control and prevention of deleterious effects upon the product;
(5) use of as few intermediate fluids as possible;
(6) use of as thin a sheet of heat-transfer wall as possible consistent with proper structural and mechanical strength;
(7) use of metals of as good heat conductivity as possible consistent with avoidance of metallic contaminations of the product.

Types of Heat Exchangers

In the *drum type heat exchanger* (Votator, Fig. 22.1), the product being processed enters and leaves through openings in the head, passing through the annular space between the heat transfer tube and the mutator shaft. The heat-transfer medium enters and leaves through connections to the jacket surrounding the heat-transfer tube and flows countercurrent to the direction of flow of the product. The heat-transfer tube separates the product from the heat-transfer medium, which can be water, steam, "Dowtherm," ammonia or brine. The mutator shaft, which rotates and carries the scraper blades, is the essential device for effecting rapid heat transfer; it maintains a homogeneous mixture or solution of the product and prevents localized overheating, for example. Choice of materials of construction and the design of the scraper blades are governed by the physical properties of the product. The rotational speed of the mutator shaft is determined by the flow characteristics of the product, the diameter of the shaft being approximately three fourths of the internal diameter of the heat-transfer tube or cylinder, thus providing a relatively small annular space. Conventional insulation is applied to the exterior of the machine.

The Votator heat exchanger is often assembled in units of two or three cylinders (see Fig. 22.3) to allow heating and cooling heat exchanges or to permit sterilizing, precooling, and final cooling operations, for example. The over-all heat-transfer coefficients are substantially greater than those normally obtained with heat exchangers of conventional design. For example, in making starch pastes for salad dressing continuously at the rate of 188 pounds per hour, an over-all heat transfer coefficient [Btu/hr) (sq ft) (°F)] of 583 was obtained while heating the mixture from 76 to 196°F. In cooling



Courtesy The Girdler Corp.

Fig. 22.3. Flow diagram showing possible assembly of three cylinders in a votator heat exchanger.

the thickened mass back to 80°F the over-all heat-transfer coefficient was 316.[3]

This type of heat exchanger is extremely versatile: it is employed in starch cooking and cooling, gelatin cooling, freezing of concentrates, chilling and plasticizing of fats and oils, sterilizing of heat-sensitive, very viscous food products in aseptic canning operations, mixing cake batters and icings, aerating marshmallows and egg whites, etc. The high ratio of heat-transfer surface to the volume of material being treated fulfills the requirement of a very high heating rate. The constant and rapid cleaning of the heat-transfer surface—1,000 to 1,400 times a minute—prevents scorching and localized overcooking. Turbulence is created by the revolving shaft and blades rather than by forcing the product at a high velocity through small diameter tube exchangers, thus eliminating the necessity for building the equipment to withstand high pressures. As a matter of fact, the pressure drop across this type of heat exchanger has to be imposed by a back pressure valve, thus making it possible to operate at a process pressure high enough to prevent flashing at the sterilization temperature. The ability to control the pressure drop across the system makes it possible to do without high-pressure pumps. The heads and shaft are readily accessible and all surfaces coming in contact with the product can be visually inspected for sanitary conditions.

The early predecessors of the Votator among drum-type heat exchangers were the so-called "flash" pasteurizers used so extensively in the creamery butter industry; the drum was steam-jacketed and the cream was swept around the internal periphery of the heater at high speed by an agitator blade. This apparatus was good for heating materials of medium viscosity to high temperature, as the scraper prevented milk solids from "burning on." These heat exchangers were not designed for high-pressure work as they were not completely sealed and were operated at atmospheric pressure.

Another early drum type of heat exchanger was the so-called batch ice cream freezer, consisting of a refrigerating drum or cylinder, usually of about

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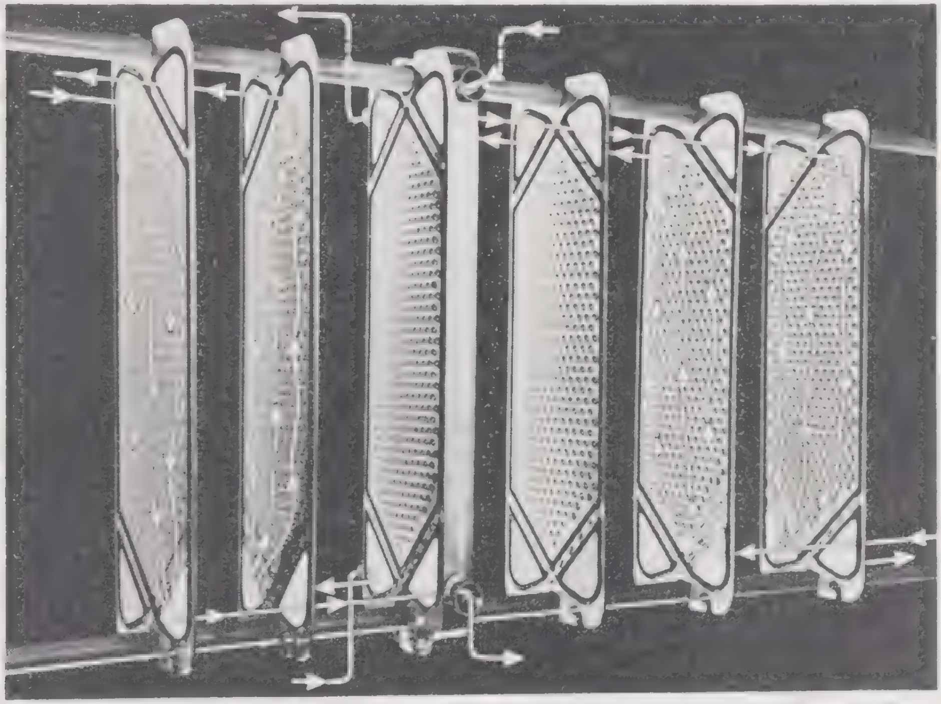
[3] Bolanowski, J. P., and Lineberry, D. D., *Ind. Eng. Chem.*, **44**, 657 (1952).

40- to 100-quart capacity, mounted on a base with direct motor drive, which turned a dasher having scrapers for removing the frozen product from the refrigerated surface and a beater for whipping air into the ice cream. This type of ice-cream freezer has been largely replaced by the continuous type, of which the Vogt freezer was the pioneer and incidentally the immediate predecessor of the Votator heat exchanger. In 1926, Vogt applied for a patent on an improved continuous ice cream freezer embodying several interesting features. He followed the old Meizenhelter principle of metering air and mix as well as freezing under pressure, but added a direct-expansion cooling system and a tube-shaped freezing cylinder which caused extremely fast freezing. This development, as well as subsequent ones, will be discussed in fuller detail later.

Plate type heat exchangers have gained wide acceptance, as they have the advantages of extreme compactness, ready accessibility for cleaning, and completely closed circuits, thus avoiding exposure of product to the atmosphere; they also have regenerative sections, which make for economic operation. The plates are usually made of thin stainless steel stampings. Very high heat-transfer rates are obtained if the flow pattern is proper and if the surface is clean. Some of the more modern plates are stamped with knobs,

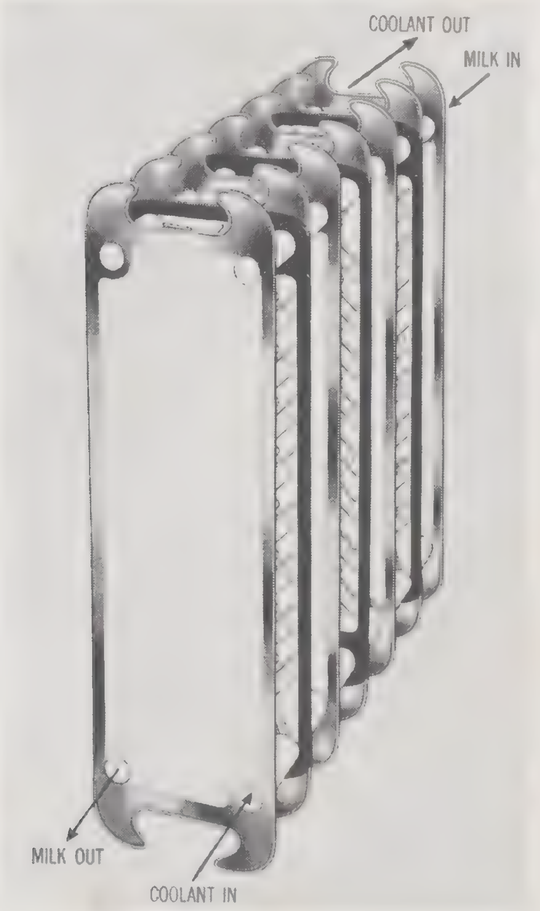


Courtesy Cherry Burrell Corp.

FIG. 22.4. This photograph illustrates how four different kinds of streams can enter or leave a single terminal plate of a plate heat-exchanger assembly without danger of intermingling.

by which the film is constantly squeezed from $\frac{1}{2}$-inch to $\frac{1}{32}$-inch thickness as it crosses each knob, thereby assuring turbulence and film stripping (see Fig. 22.4). Another manufacturer supplies smooth, solid stainless-steel plates alternated with gasket carrier plates designed with three-flow director channels at the top and bottom. The carrier plates separate the flat-head exchange plates and provide proper flow space between them; they are ridged and perforated so as to direct and control the fluid travel across the plates in a turbulent, multipass pattern for increased efficiency in heat transfer (see Fig. 22.5).

Plate heat exchangers have their broadest field of application in the dairy industry, although they are suitable for any heat-exchange purpose—heating, cooling or regeneration for any beverage or free-flowing liquid



Courtesy Creamery Package Mfg. Co.

FIG. 22.5. Diagrammatic sketch of the arrangement of smooth stainless steel heat exchange plates and gasket carriers which direct fluid flow travel across plates in a turbulent, multipass pattern.

product. In dairy applications they perform the following services:

(1) High-temperature Short-time (H.T.S.T.) pasteurization of market milk;
(2) H.T.S.T. pasteurization of milk for cheese making;
(3) full range heating or cooling of milk and cream;
(4) precooling of raw milk in receiving stations and in processing plants;
(5) preheating of milk for separating;
(6) cooling skimmilk or cream after separation;
(7) H.T.S.T. pasteurization and cooling of coffee cream, table cream, whipping cream and churning cream;
(8) cooling ice cream mix after pasteurization;
(9) heating milk prior to evaporating or drying;
(10) H.T.S.T. pasteurization and cooling of wash water for butter, cheese, etc.;
(11) milk-to-milk regeneration.

The basic heat-exchange principle in plate exchangers is simple: the product to be processed flows onto one side of the heat-exchange plate while the heating or cooling medium flows onto the other side of the same plate; thus an efficient exchange of heat is effected. In regeneration, the hot product flows onto one side of the heat-exchange plate while the cold product flows onto the other side of the same plate. The drawing in Fig. 22.6 graphically illustrates the flow of milk (or whatever product is to be handled), and the heating and cooling mediums. The drawing is purely schematic. The plates, with suitable connections and frames (or heads), are suspended on steel presses and are similar in general design to filter presses. Over-all heat-transfer coefficients frequently run from 400 to 500. Because of the ease of providing ample space, plate exchangers ordinarily use chilled raw (sweet) water for cooling, which can be supplied by means of compact direct-expansion cooler units. Hot water-circulating units are used for distributing the heating medium.

An interesting *helical screw type heat exchanger*[4] has been developed by the Bureau of Dairy Industry, U. S. Department of Agriculture, for heating milk to temperatures as high as 300°F; it has been found suitable for sterilizing, pasteurizing and preheating milk and other liquids under pressure. It has the advantages of being relatively simple and compact in design and structure, and of being readily assembled and disassembled, which makes for convenience in cleaning. Two stainless steel tapered helical screws, around which the fluid to be heated flows continuously, are seated in separate housings, the walls of which are jacketed. Water, steam, "Dowtherm", ammonia or brine can be circulated not only through the walls of the

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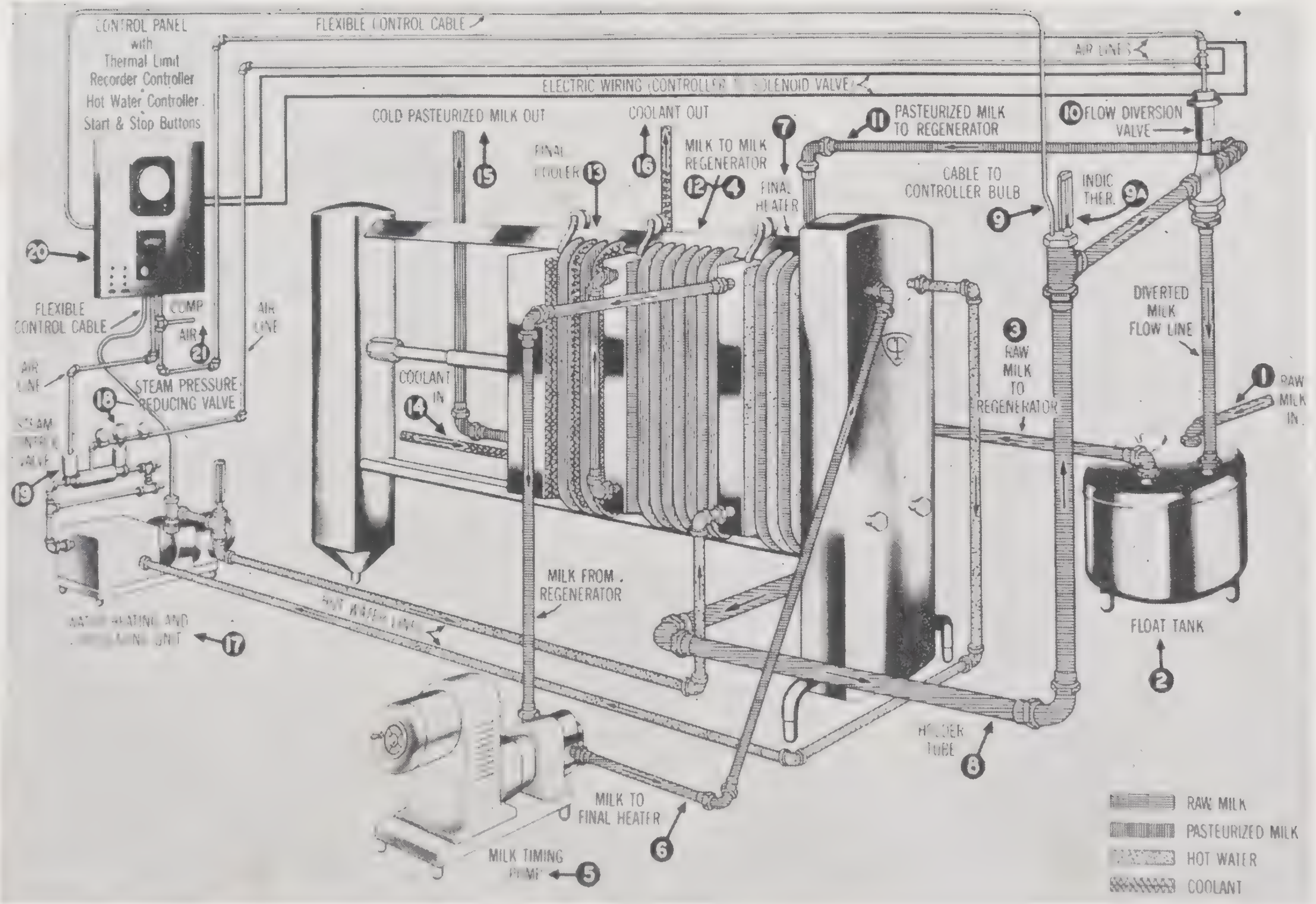
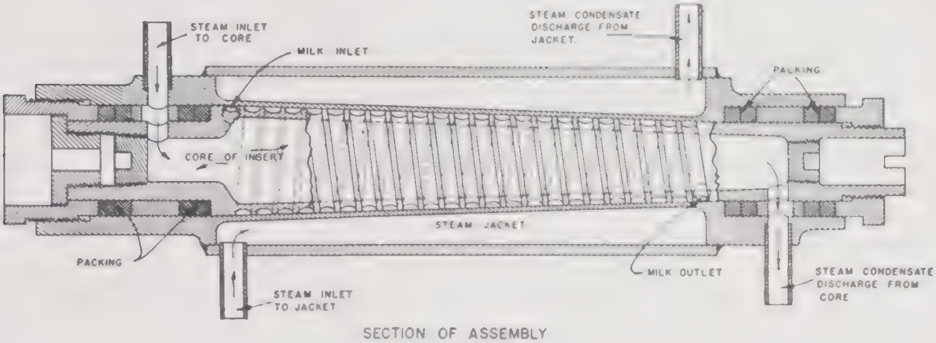
[4] U.S. Patent 2,445,115.



Courtesy Creamery Package Mfg. Co.

FIG. 22.6. Flow diagram of high-temperature short-time plate pasteurizing system.



Courtesy Bureau of Dairy Industry, USDA

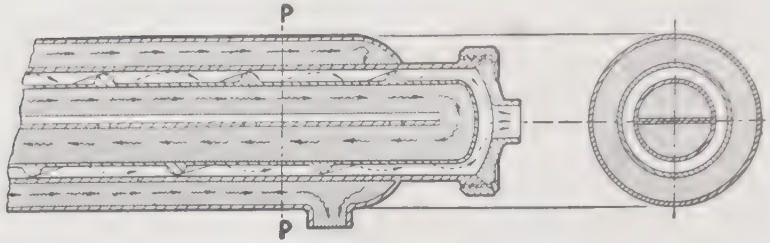
FIG. 22.7. Cross section showing assembly of helical screw heat exchanger developed for heating milk.

jackets but through the core of the screws, thus providing heat-transfer surfaces on both sides of the stream of fluid being forced through the helical channels along the periphery of the tapered screws. A section of assembly is shown in Fig. 22.7; the compactness of the equipment is illustrated in Fig. 22.8, showing the two helical screws which fit vertically in a heat exchanger having the capacity to pasteurize approximately 3,000 pounds of milk per hour.

In an improved type of heat exchanger utilizing these same basic prin

Courtesy Bureau of Dairy Industry USDA

FIG. 22.8. Dairy engineer and specialist holding the two helical screws which fit vertically in the milk heater.



Courtesy "Food Processing"

FIG. 22.9. Cross-sectional diagram of outlet end of tube of screw-type heat exchanger (also corresponds to inlet end). Note how both sides of the thin film of liquid flow in spiral fashion around annular space berween tube and helical element.

ciples of design, the heat exchanging medium is applied to both sides of a rapidly flowing thin liquid film, which travels countercurrent and in spiral fashion to the medium. Not only is rapid heat exchange achieved, but more important, the liquid adjacent to the hot metallic surface during heating is constantly pushed onward at high flow rates, so that "burn on" of milk, for example, does not occur. Design of this type of heat exchanger is shown in the cross-section diagram of the outlet end of the heating tube, within which an inner section with spiral windings replaces the helical screw described above (see Fig. 22.9). Both the inner section and the tube walls provide the heat-exchange surfaces; the heat exchange medium is circulated through both the core of the inner section or element and the jacket of the tube while the thin film of liquid flowing in spiral fashion around the annular space provided between the helical windings, or ridges, on the outer surfaces of the inner element, is heated or cooled.

Even when drastic heating is applied, no "burn on" is encountered as long as high velocity of the liquid being heated is maintained. For example, a product containing 10½ per cent milkfat and 18 per cent milk solids-not-fat with a viscosity between 10 and 15 centipoises (165°F) was heated and cooled successively in separate heat exchangers connected in series and operated at the rate of 1292 gallons per hour. The product was heated from 165 to 270°F and cooled thereafter to 145°F, only a very light deposit being found after shutting down and disassembling the units; the deposit being readily wiped off[5]. No deposit was found at the points of contact between the spiral and wall. Apparently any deposit formed during processing is continually swept off by the high-velocity flow, so that "self-cleaning" results. The over-all heat transfer coefficients of these spiral types of heat exchangers appear to be of the order of approximately 600.

Another form of screw type heat exchanger is demonstrated in two or more hollow intermeshing conveyor screws that rotate slowly in a trough or tube. The heat-exchange medium circulates through the hollow flights and shaft of the conveyor screws, while the product itself "flows" in the trough, where it is constantly rotated into, around, over and under the moving heat-exchange surfaces. The continuous mixing action causes a constant change of contact with the heat exchange surfaces, and results in a high rate of heat transfer. This type of heat exchanger, which combines mixing with heat exchanging, handles fine-grained, crystalline or powdered solids, pulps, pastes and slurries with equal facility.

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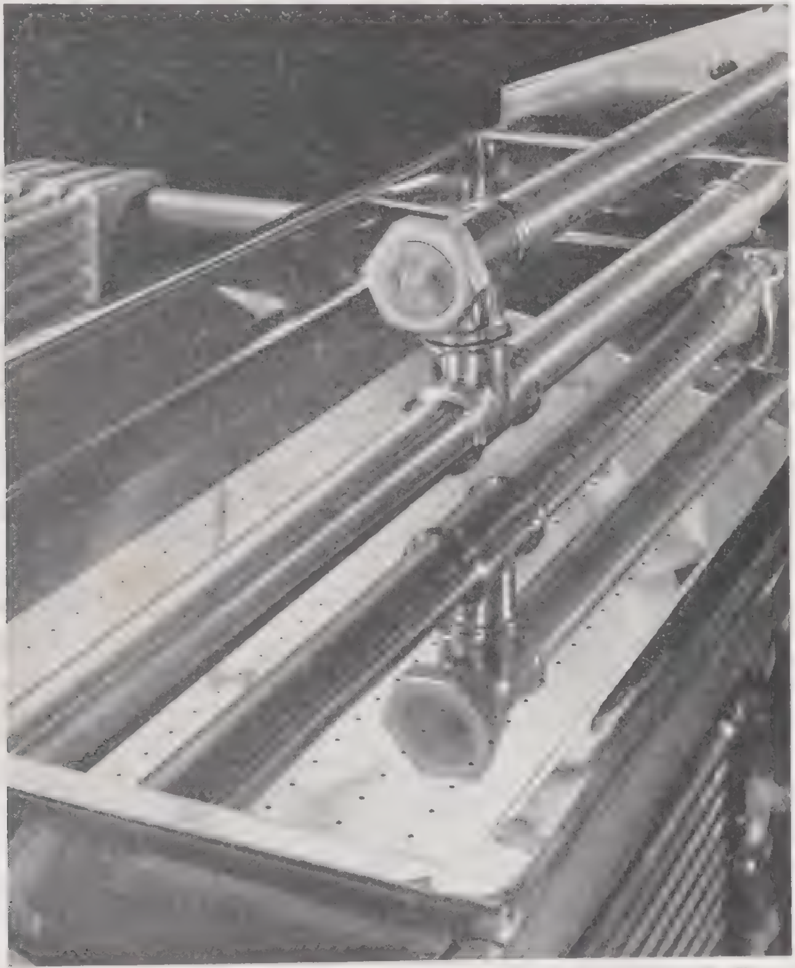
[5] *Food Processing*, **4,** 12–15 (April 1953).

The *surface tubular type heat exchanger* is used extensively for cooling purposes, as it gives rapid heat transfer and is relatively inexpensive. Some operators like it because of the aeration it provides, which, they claim,

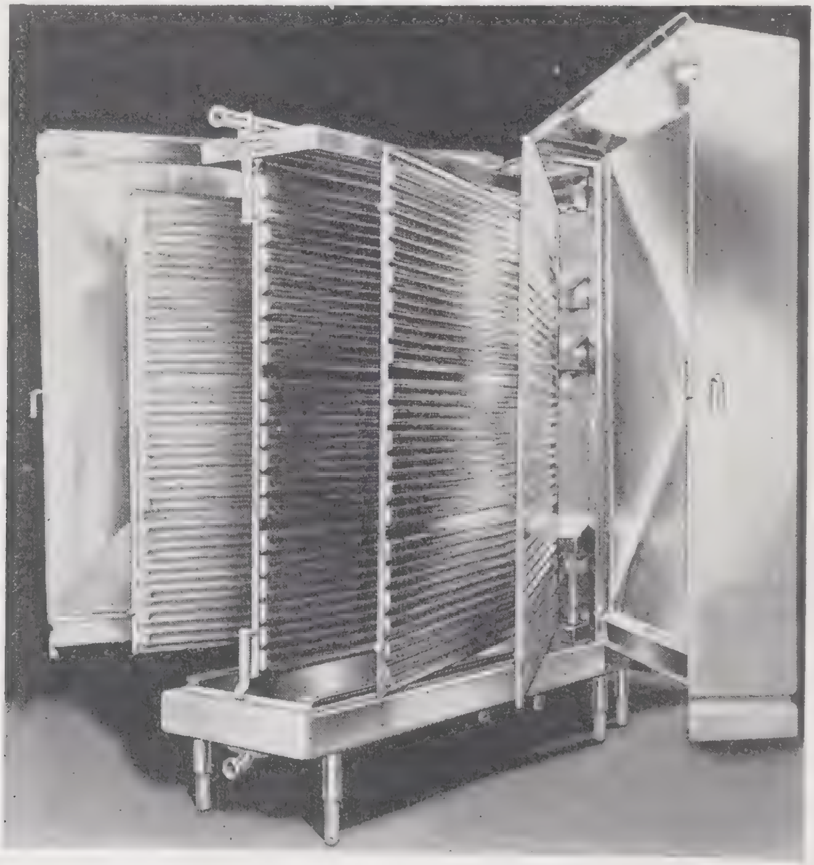


Courtesy Cherry Burrell Corp.

FIG. 22.10. Distribution trough to a surface heat exchanger. Note sanitary header tubing with perforations for distributing liquid evenly in trough and perforations in bottom of trough for distributing liquid over surface cooler section directly beneath.

improves the flavor of some products. On the other hand, it is also criticized because of its tendency to incorporate air in the products that pass over it. The heating or cooling medium is carried inside the tubes, and the product to be treated falls by gravity over the outside of the tubes. A trough at the top distributes the product (see Fig. 22.10) and a receiving trough is provided below. This apparatus is made in the so-called compact leaf type (see Fig. 22.11), having hinged sections to permit opening for cleaning purposes; it is then closed and sealed with covers during operation. The principal advantage of this design is its space-saving features and ready accessibility for cleaning purposes.

In practice, coolers are usually made in sections, for the upper portion of which cold water is the cooling medium, the lower section being cooled by circulating brine or by direct expansion of ammonia. This type of heat exchanger is flexible; however, the rate of flow must be within certain limits. If the flow is too slow, the surface will not be properly covered with product; if it is too fast, the product is apt to spatter off. A loading of about 600 pounds of a product such as milk per hour per foot length of ex-



Courtesy Cherry Burrell Corp.

FIG. 22.11. Hinged surface-type heat exchanger with covers.

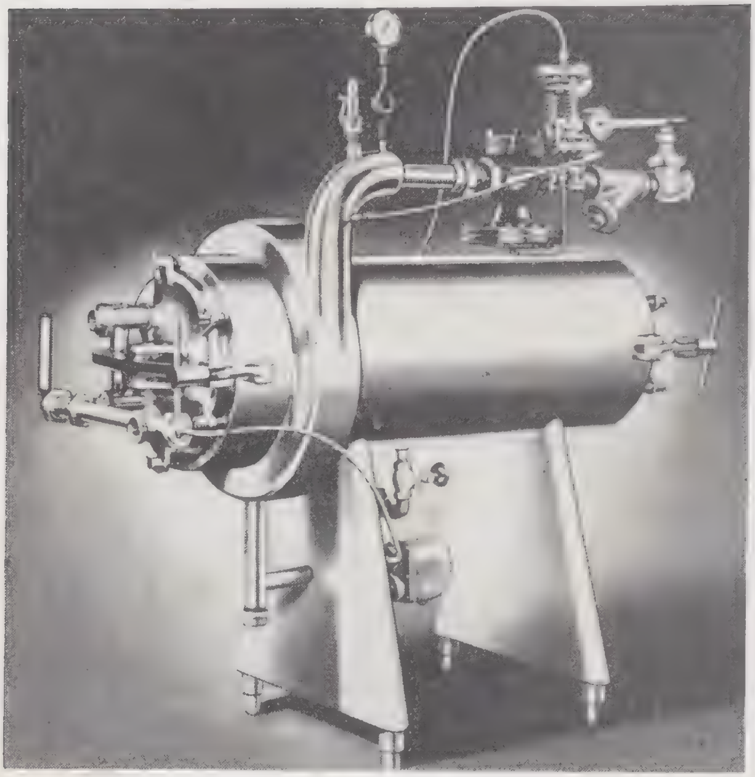
changer is considered the maximum which can safely be run over 1-inch tubes.

The heating medium used in the surface tubular type of heat exchanger is usually either hot water or low-pressure steam, which are also used in the other types of heat exchangers to be described in subsequent paragraphs. For cooling, either cold (sweet) water, brine, or direct expansion of such refrigerants such as ammonia, "Freon" or methyl chloride is used.

The *internal-tube (I.T.), double-tube, or tubular heat exchanger* has been widely used in the past for cooling and heating liquid food products. In this type of apparatus, the product passes through the inner tube and the cooling or heating medium circulates in the space between the inner and outer tubes. This type of heat exchanger has the advantage of operating as a closed system, thereby preventing evaporation loss or absorption of air. Usually, a pump is required to force the product through a heat exchanger of this type. Capacity depends largely upon the velocity of the fluids involved, the viscosity of the products treated, the amount of heating space, and the temperature difference. Usually 12 to 15 square feet of surface is allowed per 1,000 pounds per hour capacity. This type of heat exchanger is being rapidly replaced by the plate type, which is more compact, more efficient and more readily cleaned.

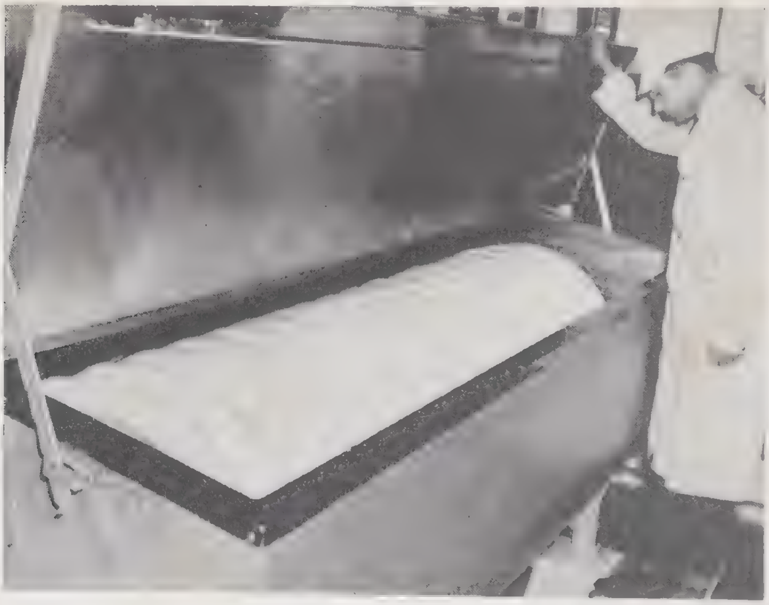
The *barrel, or shell and tube, type heat exchanger* is a compact and relatively inexpensive type frequently used in food-processing industries (see Fig. 22.12). It is similar in design to a steam-chest, the liquid product passing through tubes which are surrounded by steam. Some heaters of this type are made with an expansion head to ease the strain on the headers. Such a heater must be well trapped, so that the condensate is removed as fast as it is formed. This type of heater is usually rated at about 1,000 pounds of product such as milk per hour for each 8 square feet of heating surface. It is rapidly being replaced by drum, plate or screw-type equipment.

The *coil-type heat exchanger* was very popular with the dairy industry in years past because it gave rapid heating or cooling (see Fig. 22.13). It was used extensively as a multipurpose piece of equipment, as it could be used as a pasteurizer, a cooler and a storage vat for various batches of product. Creameries found these types of vats almost indispensable, as it was usually considered desirable to hold cream following its pasteurization and cooling in order to condition the milkfat for proper churning. It works well with either light or fairly viscous products. Its disadvantages are the difficulty of cleaning and the limitations on the amount of cooling surface which can be provided with a coil in a vat. The horizontal coil vats also have the disadvantage of incorporating considerable air in the product, although the coil can be used as a pump to circulate the heating and cooling medium through itself, from a reservoir, often attached at one end of the vat. Vertical coil vats were reputed to be superior to horizontal coil



Courtesy Mojonnier Bros. Co.

FIG. 22.12. Shell and tube heat exchanger. This 5-foot heat exchanger is used for heating liquid and semiliquid food products with low-pressure steam.



Courtesy Armour & Co.

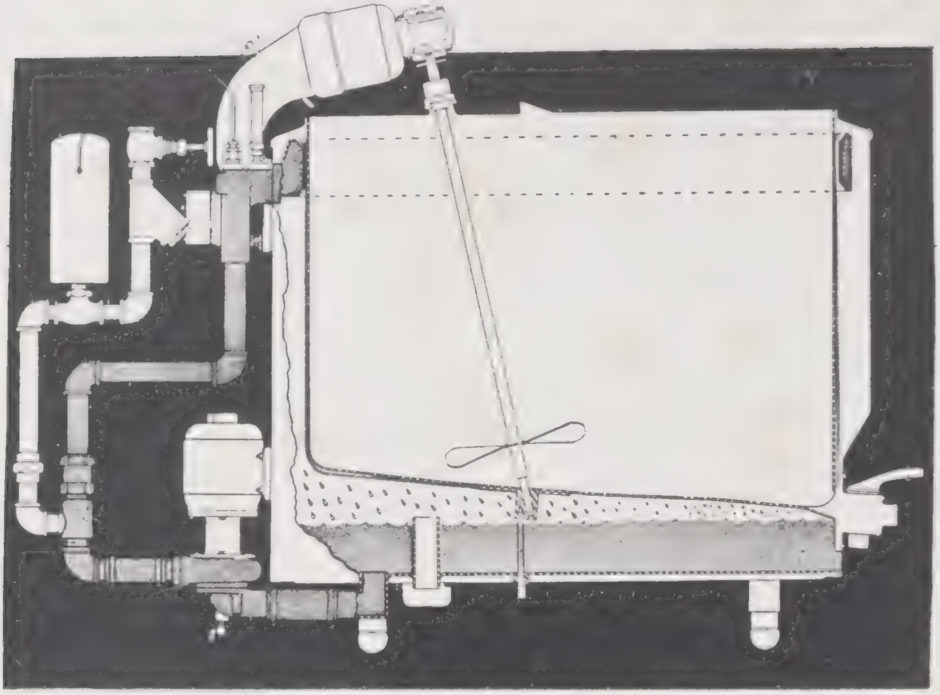
FIG. 22.13. Helical coil heat exchanger used as milk cooler in margarine manufacture.

vats, largely on the premise that they did not incorporate air into the product, but this claim was definitely disproved. They presented an additional disadvantage in that they were even more difficult to clean than the horizontal coil vats.

In the coil type heat exchangers just discussed, the coil is utilized to circulate the heat-exchange medium. In more recent years, coil heat exchangers have been developed wherein the coils are used to circulate the liquid products and are surrounded by the heating or cooling medium. High rates of heat transfer have been attained by circulating the liquids through the coils at high velocities, the walls of the coils providing the heat-transfer surfaces. In heating applications, high-pressure steam has been used as the heating medium, permitting the use of sterilizing temperatures (250-300°F). These heat exchangers have been limited in their applications because of the practical difficulties encountered with "burn on" as the deposits accumulate and eventually prevent effective performance. While high heat-transfer rates have been attained, another major disadvantage of this type of heat exchanger has been the difficulty of cleaning, coupled with the difficulty of inspecting their sanitary condition.

The flat-surface type heat exchanger utilizes the walls of a tank or of a hollow plate suspended in the vat as the heat-transfer surface. Both forms are inherently adapted to self-contained heating and cooling systems. The great advantages are simplicity, low first cost and ease of cleaning. The limitation of the amount of surface available for heat transfer has been augmented in more recent years by the spray system of heating and cooling, or forced circulation in channels. The heating or cooling medium is pumped to a spray-ring surrounding the side-wall lining of such tanks, and flows on this heat-transfer surface in a fast-moving, continuous film. Heat is rapidly transferred, so that liquid products such as milk are heated (or cooled) quickly to the desired temperature. Heat transfer is expedited by agitating the liquid product within the tank sufficiently to remove its film from the heat-transfer surface. This principle of heating milk has permitted the use of relatively low-temperature heating water, so that no "burn-on," scorching, or overheating occurs. By controlling the degree of agitation, it is possible to pasteurize and cool milk in the same vat, as well as to retain natural flavor and deep cream line. The flavor is impaired by any cooked tastes, and the cream line is reduced or destroyed by too much agitation or too slow heating and cooling.

The proper design of a flat-surface spray-type heat exchanger is illustrated in the cross-section drawing of Fig. 22.14. Note that the level of the overflow pipe is well below the lowest point of the inner lining (or heat-transfer surface) of the vat. It is so constructed that when the desired temperature has been reached and the pump has stopped, the circulating

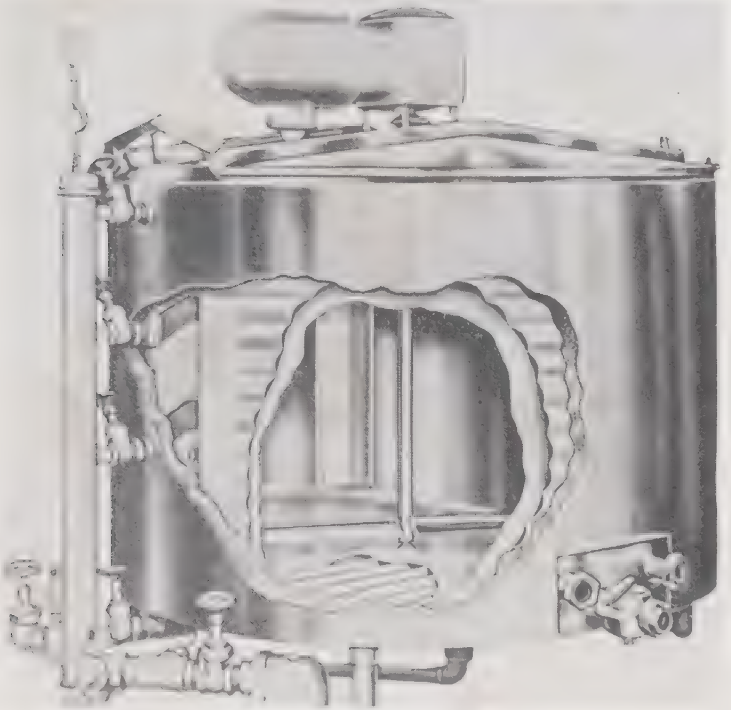


Courtesy Cherry-Burrell Corp.

FIG. 22.14. Flat-surface heat exchanger equipped with spray header for distributing film of heat-exchanging medium over heat-transfer surface side wall which collects and drains out overflow outlet so as not to flood jacketed area between inner and outer side walls of exchanger.

water drops completely away from the lining. This results in no creep in the final temperature of the milk and thus avoids overpasteurization, which causes development of cooked flavor. The relatively low temperature heating water is circulated by a high-capacity pump, which forms a film around the inner lining of the vat. It is conveyed onto the lining in a large volume so that it clings in a film until it reaches the lowest point in the vat. Here it falls to the bottom, from which it is recirculated, being reheated thermostatically in the cycle. During the cooling cycle, cold water replaces the heated water until the product reaches the desired temperature. Other cooling mediums can be used if desired.

Another interesting design of smooth-surface heat exchanger is a mixing tank for handling viscous or macerated food products that must be heated and cooled in bulk. Such material obviously cannot be readily pumped through separate coolers. Therefore, a jacketed mixing tank having high-pressure channels in the side wall and bottom, permitting forced circulation of many types of heating and cooling mediums, has found extensive use as a flat-surface heat exchanger. Heat-transfer rates are high because the heat-exchange medium can be circulated around the vat side wall and



Courtesy Monjonnier Bros. Co.

Fig. 22.15. Another type of flat surface heat exchanger showing cut-away section of inner heat transfer side walls and bottom surrounded by channel and outer insulated side walls and bottom. This arrangement permits forced circulation of high-velocity heating and cooling mediums.

bottom at high velocity (see Fig. 21.15.) These vats are provided with the proper design of agitator consistent with the demands of the products processed, and can be designed to operate under vacuum or pressure. Even direct expansion of ammonia for cooling purposes can be provided.

There are, of course, many modifications in design, construction and operation of the foregoing types of heat exchangers which we have not discussed or outlined. Product characteristics generally dictate design, as well as structural and mechanical characteristics. Consequently, the variations in the design and performance of heat exchangers are virtually endless. We have endeavored to include representative types with as wide a range of application as is normally encountered in the heat exchangers used in the food-processing industries.

We have left until last the discussion of *the direct injection of heat exchange mediums.* Obviously, when processing permits mixing food products with either ice cold water or steam, we can thereby attain a maximum efficiency of heat exchange. Heating by direct steam injection is more or less frowned upon by most health authorities on account of possible contamination from boiler compounds, corrosion products, etc. Then too, direct injection of steam can contribute to many quality defects due to dilution and contamination. Nevertheless, it is used in a number of processes with beneficial effects. The steam must be broken up with a number of fine jets in order to give smooth action and distribution. Usually nozzles or spiders equipped with various slits or fine holes are utilized in direct steam injection. Suitable traps, strainers and filters are also used to purify the steam before it reaches the nozzles.

Steam added to a product by direct injection condenses and thus adds water, and this fact has to be taken into consideration. Normally, 1 per cent dilution is contributed by every 10°F increase in temperature during heating. For that reason, direct steam injection is usually applied during the later stages of heating, to minimize dilution effects. The Grindrod processes of multiple treatments of fluid food products at high temperatures, which give unusually good bactericidal effects and specific physical characteristics, require the injection of live steam.

H. T. S. T. Pasteurization and "Sterilization"

The foregoing discussions have been limited to those types of heat exchangers normally used in food-processing industries in providing heat transfer by conduction to fluid films, coupled with heat transfer by forced convection to liquid and semiliquid food masses. We wish to emphasize the fact that satisfactory performance of these exchangers depends upon proper treatment of films of either the heat-transfer mediums or of the products being heated or cooled, or both. And we have observed the importance of the factors of agitation provided by mixing and pumping in assuring efficient heat transfer or exchange.

It should also be pointed out that the types of heat exchangers (such as we have just discussed) have been utilized in the past primarily to process many foods just short of "commercially sterilizing" them. The term "commercially sterilizing" is used in the sense of its definition by Tanner to the effect that "canned food may contain viable spores of a type, such as the thermophilic, which will not develop under conditions that are normally maintained during storage of the food"[6]. For, to sterilize in the sense of the absolute destruction of all living organisms, it would probably be necessary to overcook most foods to such an extent that they would be unsuitable for sale.

Recent developments utilizing the principle of aseptic processing have created the demand for heat exchangers that would more nearly sterilize liquid foods than has heretofore been the case. According to Ball[6], asepsis implies the absence of microorganisms in a food and a continued protection of the food from contamination with microorganisms. Therefore, as aseptic processing of food is now utilizing principles that were first revealed in pasteurizing practices, a few paragraphs may well be devoted to a discussion of *high-temperature short-time* (*H.T.S.T.*) *pasteurization and "sterilization,"* in which the food engineering aspects are emphasized.

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[6] Ball, C. O., *Food Research*, **3**, 13–52 (1938).

Pasteurization is practiced in the modern dairy as well as in any other food-processing plants primarily for the purposes of (1) making the food so treated safe for human consumption, and (2) prolonging its keeping qualities. The pasteurizing process consists, in principle, of heating the product to a predetermined temperature and holding it at that temperature *for a time sufficient to kill all the pathogenic bacteria and, in fact, nearly all the microorganisms present* (*99 + %*). By so doing, the product is rendered safe from a public health standpoint, and its keeping quality is considerably enhanced. However, pasteurized foods do not have the shelf-life of commercially sterilized (canned) foods, and to retain their acceptability, they normally need a moderate amount of refrigeration. Unless pasteurization is utilized to prepare the food for some subsequent processing that provides a prolonged keeping quality (e.g. pasteurizing milk for cheese making), its shelf-life, even with refrigeration, is relatively short compared to that of canned foods. As a matter of fact, the original work with the process by Louis Pasteur, its discoverer, was done to prevent wines from souring.

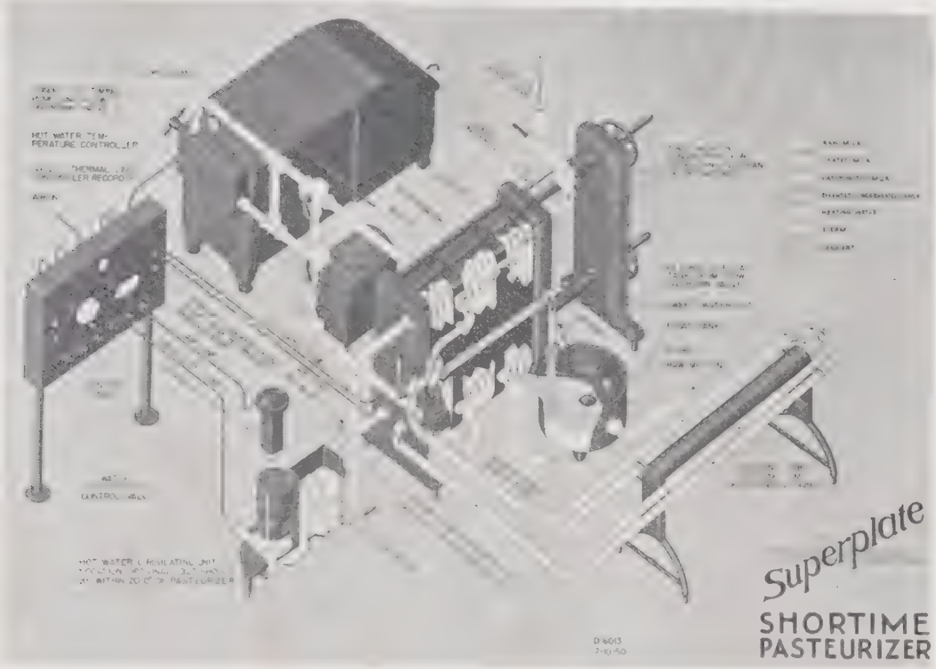
Consequently, in pasteurizing milk to prevent it from souring, the apparatus used must be so designed as to heat every cubic centimeter of milk to the proper temperature for the required length of time, and to do it accurately, since overheating impairs its acceptability (i.e. its flavor and its "cream line"), and underheating impairs its public health safety. Inasmuch as it is unnecessary to discuss all the technical details involved in assuring "perfect" pasteurization—and it must be "perfect" to provide adequate health protection—we shall merely mention the salient engineering features. A plain batch-type pasteurizer can be provided by most of the various types of heat exchangers previously discussed; however, for purposes of illustration we shall refer to the smooth-surface spray vat just described.

This type of pasteurizer consists mainly of a stainless steel tank, a means of agitating the milk, and a heat-transfer surface. These pasteurizers are simple and inexpensive where the quantity of milk to be handled does not exceed 500 to 1,000 gallons. Ordinarily, they are manually controlled, although they may be equipped with automatic controls and are so required by the health authorities of some communities. They can be fitted with all manner of accessories, such as foam heaters, recording thermometers, leak protector valves, etc. They are necessarily slower in heating than the continuous pasteurizer, because the heating surface is relatively limited, although these tanks can be used for cooling as well as heating. Agitation is an important consideration in a pasteurizer of this sort, as it must be sufficient to prevent "burning on" without injuring the cream line, as previously mentioned.

No detailed description will be given of the various types of continuous pasteurizers that could be used, and probably are being used, in various parts of the country. However, it should be emphasized that the batch type of pasteurizer normally heats milk to 142–145°F and holds it there for at least 30 minutes before cooling; the continuous type heats milk to 165–168°F and holds it for approximately 20 seconds by continuously passing it through a short tube, thereby providing the necessary time for adequate pasteurization before cooling begins. Very accurate temperature control is essential in operating continuous systems; they are usually equipped with safety devices, such as flow diversion valves, as the time interval is short and great care must be exercised to prevent unpasteurized milk from being passed through. The change from batch to continuous operations was due to the rather obvious advantage of economy, as well as to the superior flavor of the so-called high-temperature short-time (H.T.S.T.) pasteurized milk. With the advent of the plate type heat exchanger and its adaptation to the continuous pasteurization of milk, completely automatic and fully protected systems have been developed and approved by health authorities throughout the country (see Fig. 22.16).

The H.T.S.T. process of pasteurization has a number of advantages, such as lower first cost, lower cost of operation due to regeneration on heating and cooling, and the fact the pasteurized milk can be drawn off a few seconds after starting, thus saving time in various plant operations. Cleaning time is usually considerably less than with the old holding method of operation. The application of the principle of regeneration is of great value, as the outgoing hot milk partially heats the incoming cold milk, and vice versa. A regenerator efficiency of 80 per cent is often realized. Some systems use milk-to-milk regeneration, whereas others use milk-to-water. With the first system, the efficiency is usually greater and there is less equipment to clean, but the pasteurized milk must be at greater pressure than the incoming cold milk, to prevent contamination in case of a leak.

These advantages of the H.T.S.T. method of pasteurization are significant to a food engineer, for they can also accrue to the food processor who utilizes the same principles in the aseptic processing of foods requiring commercial sterilization for preservation. The only differences involved are those of degree. The Martin process of aseptic canning has attracted considerable interest among food processors, and is daily being extended to more and more food products. It is basically one that employs properly designed heat exchangers to sterilize foods commercially in the shortest



Courtesy Cherry-Burrell Corp.

FIG. 22.16. Flow diagram of a typical automatic high-temperature short-time pasteurizer assembly.

possible time; it then rapidly cools the processed food in another heat exchanger, and is followed by the packaging and sealing of the cooled, sterilized food product in a previously sterilized container. The entire processing equipment is carefully cleaned and thoroughly sterilized before use. On the other hand, pasteurized foods are so treated as to destroy disease bearing microorganisms, as well as those which impair normal keeping qualities. Such products are so packaged as to minimize the possibility of any serious contamination. High-temperature short-time (H.T.S.T.) techniques in pasteurization and aseptic food processing have the advantages of both economy and maximum retention of product acceptability (flavor, taste color and appearance) and nutritional (vitamins and other essential food factors) qualities.

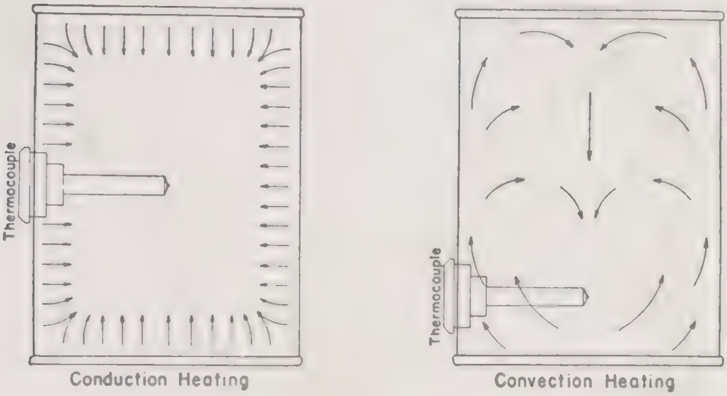
Vacuum Pasteurization

Considerable interest was manifested in the past in so-called "vacuum pasteurization" of milk and cream. The product was heated considerably above normal pasteurizing temperatures, sometimes as high as 250°F, followed by immediate "flashing" into a vacuum chamber, which reduced the temperature to one corresponding to the degree of vacuum maintained. The sudden reduction in pressure caused certain volatile substances to pass off and to be entrained in the exhausting system and eventually eliminated, thus removing condensible and noncondensible vapors, with a resulting reduction of flavor. This system of pasteurization is presently being applied by the use of the Vacreator for processing cream for buttermaking and ice cream mix, and milk for cheese and other products. The Vacreator has three connected stainless stell chambers, each capable of maintaining reduced pressure: the first chamber usually is maintained at from 11 to 6½ inch vacuum, the second chamber at from 20 to 15 inch vacuum, and the third chamber at approximately 28 inch vacuum. The corresponding temperatures of the product in these three chambers are approximately 190 to 200°F, 160 to 180°F, and 100°F. The first chamber is the pasteurizing chamber, as steam is admitted continuously and reduced to the temperature of pasteurization. The various chambers provide for the removal of vapors, thereby providing for vapor washing of the products under treatment. Vacuum pasteurization is, in effect, a combined heating, precooling, and evaporating operation, as considerable water vapor is removed in the vacuum chambers; approximately 1 per cent of water for each 10°F drop in temperature is removed from the liquids so treated.

HEATING BY CONVECTION

The second method of heat exchanging is by convection, that is, by currents in a liquid or gaseous substance. It involves the transfer of heat from one point to another in a fluid, or between a fluid and a solid or another fluid, by the movement of mixing of the fluids involved. As stated earlier, if the changes in temperature create differences in density and thus impart motion to the fluid, the operation is called *natural* convection, whereas if the motion is produced by mechanical means, the operation is known as *forced* convection. Although the transfer of heat by convection in the thermal processing of foods has been extensively studied, the formation of an exact quantitative theory has not been fully realized as yet.

Natural convection is illustrated by the currents set up in a cold-storage room by settling of the cold air around the refrigerating coils to the bottom of the room and the warm air rising. This circulation of natural currents stimulates the exchange of heat throughout the room until equilibrium is eventually established. Or the cold-storage room may be cooled more quickly by using fans to increase air circulation by forced convection. Convection heat transfer is also demonstrated in the heating of sealed cans of certain foods in a steam pressure retort, for example, clear soups and most brine-packed vegetables. On the other hand, canned products such as cream-style corn, thickened concentrated soups, pumpkin and most meat products which do not develop convection currents due to their viscosities, are conduction-heated. The mechanism of these two types of



Courtesy American Can Co.

FIG. 22.17. Mechanism of heat penetration.

heat penetration in metal cans is illustrated in Fig. 22.17. As a matter of fact, convection heating of the contents of sealed cans of food is always accompanied by some conduction, as the metal tops and bodies of the cans provide heat-transfer surfaces.

In heating materials in cans by convection a limiting condition would represent "perfect" convection; that is, convection currents of such rapidity that all portions of the liquid in the can are at the same temperature at the same time. In such a case, the rate of temperature rise at any given time will depend largely on the ratio of can surface to can volume, and on the difference between the temperature of the liquid and the temperature of the heating medium. Such a condition would bring about a logarithmic time-temperature relationship such as the limiting condition for heat transfer by conduction. Obviously any resistance to flow in the liquid would cause some departure from this condition of perfect convection; and the film-transfer lags both inside and outside the container must also be considered.

Heat is the most valuable preserving agent for foods now known. Knowledge of radiation absorption techniques is growing and indicates eventual development of methods of the "cold sterilization" of foods; but its technology has not yet developed to the point where its commercial application is assured. Therefore, discovery of the principle of sterilization by heat and initial development of the art of heat processing by Appert still stands as the most outstanding accomplishment in the history of food preservation—an art that has provided the basis for most of our present industrial food-processing industries. Heat processing of foods in sealed metal containers under pressure remains today the most satisfactory method of sterilizing canned foods of low acidity. Methods of application appear, however, to be emerging from "in-the-can" thermal processings to those utilizing aseptic principles, with apparent advantages to certain foods continuously and more expeditiously processed before being sealed in aseptic containers.

Sterilizing retort processes often impair the quality of nonacidic products (such as vegetables, sea foods, meats, etc.)—a fact which the industries involved have long recognized. Consequently, constant effort not only to develop improved methods of preservation but also to learn more about the thermal sterilizing processes themselves is being carried out. In fact, the development of many "high-short" (referring to high-temperature short-time) methods of processing nonacidic foods and the adoption of aseptic canning procedures have been stimulated by the unending quest for better foods—that is, not only better tasting but more nutritious. In the search for means of improving thermal processing, some of the most helpful contributions have come from better methods of measuring and interpreting heat penetration in canned foods.

For the production of retort-processed foods having color and flavor which are most nearly like those of home-cooked foods, commercial processing with pressure retorts must be such that (1) every container receives the same treatment, (2) the retort is heated rapidly to its holding temperature, and (3) the containers and their contents are cooled rapidly. Such so-called "still" retort operating techniques have been improved largely because of four essential steps taken since the introduction of the steam pressure retort in the thermal processing of foods:

(1) the introduction of indicating pressure gages and indicating thermometers as retort equipment;
(2) the change from the internal generation of steam to the piping of externally generated steam into the retort;
(3) the studies of heat penetration into the container and of temperature distribution within the retort;
(4) the introduction of automatic temperature and pressure controllers.

Significance of Heat Penetration Testing

The measurement of temperature at the slowest heating point within a sealed can of food as it is being processed is known as "heat penetration testing." In some of the earliest heat penetration studies, maximum thermometers were placed inside the sealed can, as reported by Kochs and Weinhausen[7]. The use of thermocouples for heat penetration measurement in cans and for studying variations in temperature within a retort in 1907 and 1914 respectively was reported by Bitting and Bitting[8]. Extensive tests using thermocouples were described by Thompson[9], who is

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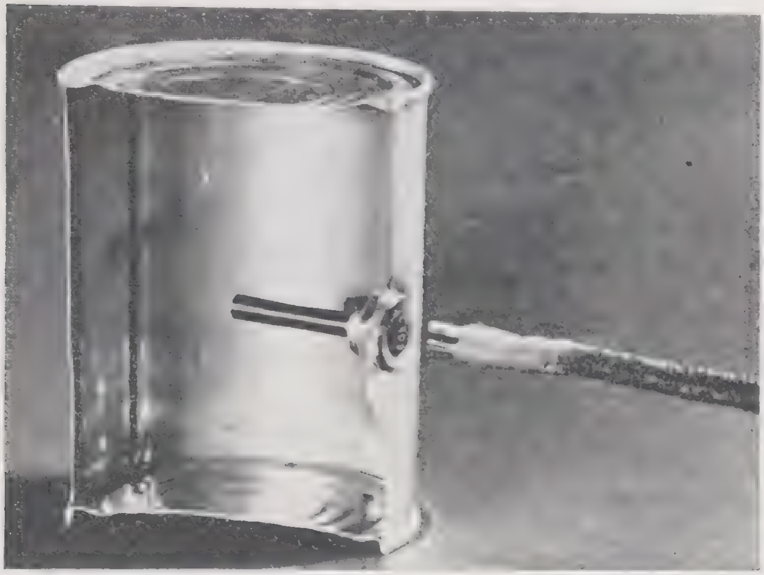
[7] Kochs and Weinhausen, *Ber. K. Gart. Lehranst.*, Dahlem, 146 (1906–07).

[8] Bitting, A. W., and Bitting, K. G., *Natl. Canners' Assoc. Bull.*, **14**, (December, 1917).

[9] Thompson, Geo. E., *Ind. Eng. Chem.*, **11**, 657 (1919).



Courtesy American Can Co.

FIG. 22.18. Nonprojecting type of thermocouple installation in can showing leads to potentiometer.

credited with the development of some of the basic equations describing the rate of heat penetration in canned foods. Many other investigators have contributed significant knowledge to the design and use of thermocouples for heat penetration measurements. Ecklund[10] designed a thermocouple which does not project from the side of the test can (see Fig. 22.16), and described complete specialized heat penetration equipment based upon this thermocouple, which now has wide application in the conduct of heat penetration tests. Until recently process determinations for canned food products were made mostly by the research laboratories of can manufacturers and a few food processors. Now, however, many laboratories interested in canning technology are equipped for conducting tests to establish efficient process schedules.

The first step in conducting a heat penetration test involves placing the thermocouple in the test cans (see Fig. 22.18). For products heated by conduction, the thermocouples should be placed so that the hot junctions (located at the tips of the thermocouples) are located at the geometric centers of the cans. For products heated by convection, the thermocouple tips should be located on the can axis at a point near the bottom; for No. 2 cans this point is about $^3/_4$ inch above the bottom and for No. 10 cans about $1^1/_2$ inches above the bottom, when the cans are processed in an upright position.

The objective of heat penetration determinations is, of course, to obtain data to be used in process calculations. Three methods are commonly used in analyzing the data so obtained; these are usually referred to as the graphical method (Bigelow, Bohart, Richardson and Ball[11]), the formula method (Ball[12, 13]), and the nomogram method (Olson and Stevens[14]). These have been ably and effectively summarized in an excellent brochure by the American Can Company Research Division to which the reader is referred for an authoritative source of useful information[15]. Other methods of analysis have been described by Stumbo[16, 17], Hicks[18], and Gillespy[19] and ably analyzed by Hicks[20]. All these latter workers have approached the problem on the premise that there is probably survival of spoilage organisms throughout a can's contents and not just at the can center. There is little likelihood that their results will materially alter the process calculation methods already established and widely used.

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[10] Ecklund, O. F., *Food Technol.*, **3**, 231 (1949).

The mechanics and interpretation of heat penetration tests in canned foods has been recently summarized and discussed in significant detail by Alstrand and Ecklund[21]; this work is also recommended for its concise and pertinent discussion of the subject.

Sterilizing Value

Both time and temperature are essential elements in the sterilization of canned foods. Sterilization cannot be achieved simply by the attainment of certain temperatures in the can center. For every temperature there is a time element that must be satisfied to destroy bacteria, just as the time element is also critical in proper pasteurization practice. Using the methods developed by Ball, the amount of lethal heat at the slowest heating point in the can is totaled and is expressed as the sterilizing value (F_0) of the process. The F_0 value has been defined as the equivalent number of minutes at 250°F (121.1°C) when no time is required to heat to 250°F or cool to sublethal temperatures and when the thermal death time surve slope (z) is equal to 18°F. The z value is the temperature difference between two points on the termal death time curve which differ by a multiple of 10 on the time scale. Although this value is subject to some variation, an average value of 18°F has worked out well in practice.

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[11] Bigelow, W. D., Bohart, G. S., Richardson, A. C., and Ball, C. O., *Natl. Canners' Assoc. Bull.*, **16-L** (August, 1920).

[12] Ball, C. O., *Natl. Research Council Bull.*, **7** (1923).

[13] Ball, C. O., *Univ. Calif. (Berkeley), Publ. Public Health*, **1** (1928).

[14] Olson, F. C. W., and Stevens, H. P., *Food Research*, **4**, 1 (1939).

[15] American Can Co., Research Division, Maywood, Ill., "Calculation of processes for canned foods," January 1950.

[16] Stumbo, C. H., *Food Technol.*, **2**, 115 (1948).

[17] Stumbo, C. H., *Food Technol.*, **3**, 126 (1949).

[18] Hicks, E. W., *Food Technol.*, **4**, 134 (1951).

[19] Gillespy, T. G., *Sci. Food Agr.*, **3**, 107 (1951).

[20] Hicks, E. W., *Food Technol.* **5**, 175 (1952).

[21] Alstrand, D. V., and Ecklund, O. F., *Food Technol.*, **5**, 185 (1952)

From the proper heat penetration data, it is possible to evaluate the amount of sterilizing heat supplied by a specific process for the product tested. Conversely, it is possible to start with a specific sterilizing value and calculate the processing time at a given retort temperature. Consequently, since the process time and sterilizing value are dependable variables, one must be known in order to calculate the other. Thermal death time tests are sometimes necessary to aid in establishing satisfactory sterilizing values. Small glass tubes or small cans of the product involved are inoculated with spores of a resistant organism, sealed, subjected to various processes, and incubated or subcultured to determine the thermal resistance of the organism in the product for which a process is to be determined.

Most often, however, established processes which have given satisfactory results for many years are used as yardsticks in selecting sterilizing values to be used in process calculations for new products. As an example, calculated sterilizing values for some commercial processes are shown in Table 22.1, as published by Alstrand and Ecklund[21]. Similar values are available in a variety of sources.

As indicated in Table 22.1, the same sterilizing value is not always used for both large and small cans of the same product. The tendency is to use higher sterilizing values for the larger can sizes of convection-heated products and lower sterilizing values for larger can sizes of conduction-heated products. Heat penetration tests and inoculation studies by Sognefest and Benjamin[22] confirm the need for higher sterilizing values in larger cans of convection-heated products. Processing studies on No. 2 and No. 10 canned peas indicated the need for 22 to 44 per cent higher sterilizing value for the latter. Similar studies of brine-packed whole kernel corn, although somewhat less reliable because of the variable rate of heating the product, also indicated the need of a somewhat higher sterilizing value for the larger can size. The necessity for higher sterilizing values for large cans of convection-heated products may be partially explained by the fact that the larger cans contain several times more spores than the smaller ones. Because of liquid circulation in the product, all organisms receive substantially the same heat treatment. If both can sizes received equivalent sterilizing values, more probability of spoilage would exist for cans containing the larger number of spores.

Sognefest, Hays, Wheaton and Benjamin[23] reported extensive thermal

[22] Sognefest, P., and Benjamin, H. A., Minutes of Processing Conference of Natl. Canners Assn., 1943.

[23] Sognefest, P., Hays, G. L., Wheaton, E., and Benjamin, H. A., *Food Research*, **13**, 400 (1948).

TABLE 22.1. CALCULATED STERILIZING VALUE (F_0) FOR SOME CURRENT COMMERCIAL PROCESSES[21]

Product	Can Sizes	Approximate Calculated Sterilizing Value (F_0)
Asparagus	All	2–4
Green beans, brine packed	No. 2	3.5
Green beans, brine packed	No. 10	6
Chicken, boned	All	6–8
Corn, whole kernel, brine packed	No. 2	9
Corn, whole kernel, brine packed	No. 10	15
Cream style corn	No. 2	5–6
Cream style corn	No. 10	2.3*
Dog food	No. 2	12
Dog food	No. 10	6
Mackerel in brine	301 × 411	2.9–3.6
Meat loaf	No. 2	6
Peas, brine packed	No. 2	7
Peas, brine packed	No. 10	11
Sausage, Vienna, in brine	Various	5
Chili con carne	Various	6

* The actual sterilizing values of No. 10 cream style corn cooled under pressure may be twice as high as the calculated values, as shown by Hemler, Alstrand, Ecklund and Benjamin (in press). The calculated F_0 values for conduction heating products are based on the slope of the cooling curve the same as the heating curve with a constant lag factor. Packing or processing conditions which vary the cooling curve slope are not taken into account in the formula method.

death time can studies on the effect of pH on the thermal process requirements for vegetable purees. In this work it has been noted that the carbohydrate content of the food, as well as the pH, has a marked effect on the thermal resistance of test organism P.A. 3679. Based on the correlation found between pH, carbohydrate content and thermal resistance, the figures in Table 22.2 may be useful as a guide in the selection of sterilizing values. Although no meat products were included in the tests on which Table 22.2 was based, the values do not appear to be out of line for meat products[21].

TABLE 22.2. PROPOSED STERILIZING VALUES (F_0) IN RELATION TO pH AND CARBOHYDRATE CONTENT OF CANNED FOODS[21]

pH of Product before Heating	Per cent Carbohydrate in Canned Vegetable Products		
	3–6	9–12	15 plus
4.5 to 5.0	0.5	1.0	2.0
5.0 to 6.0	3.0	4.5	6.0
6.0 and above	4.0	6.0	8.0

* The 3–6% range includes all products in groups 1 and 2, the 9–12% range includes all products in groups 3 and 4, and the 15% and above includes all products in groups 5, 6 and "miscellaneous high" as classified by Chatfield and Adams, *USDA Circ. 549* (1949).

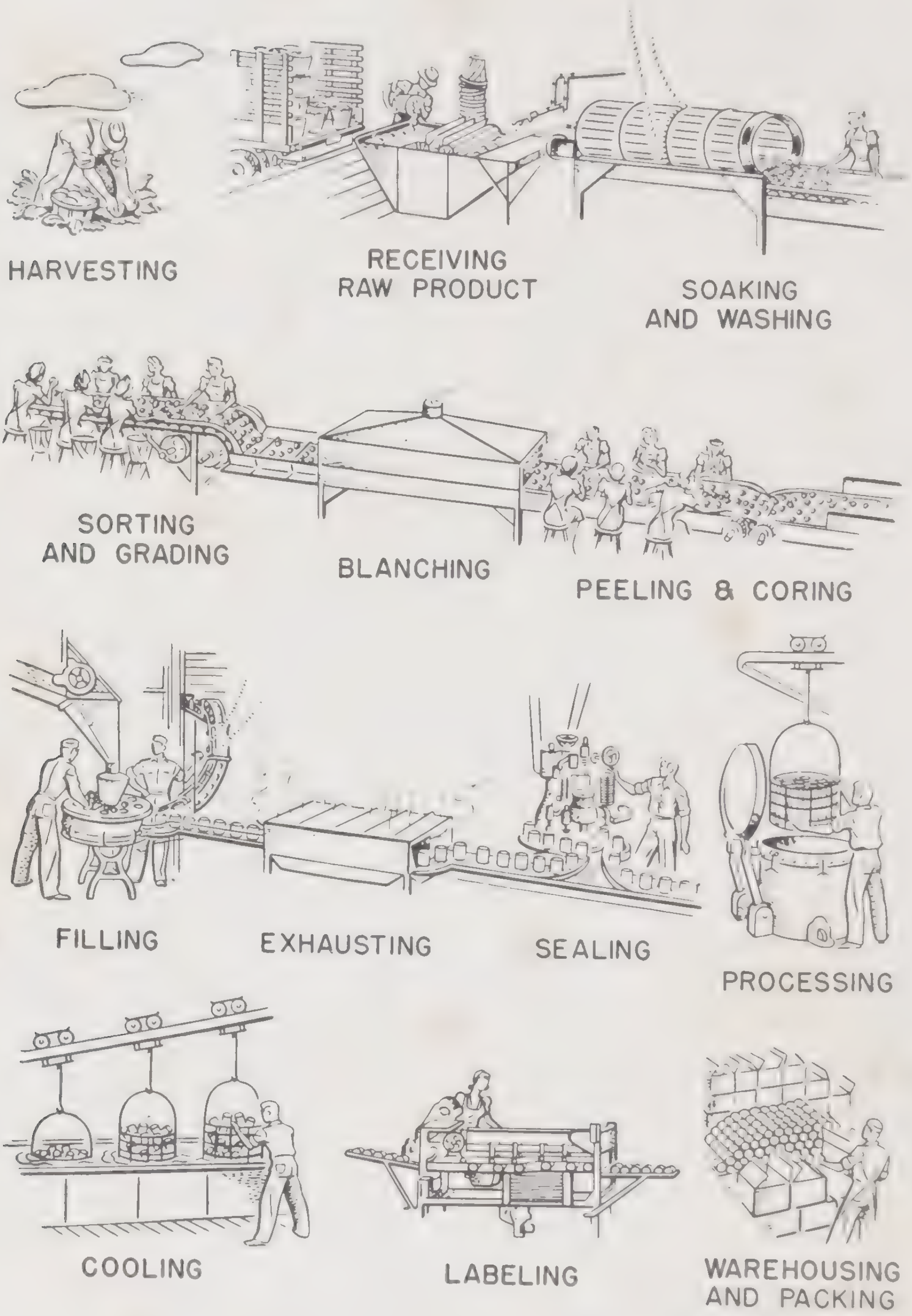
Thermal Processing

The procedures followed in preparing various food products for canning or glass packing have been described in several chapters in this book. These vary with the product, but generally the raw material is freed of all foreign substances or undesirable particles and is carefully inspected and trimmed free of imperfections and obvious faults. Later operations vary with the food product, although the usual sequence of the unit operations is depicted in Fig. 22.19. Of those listed, the ones of consequence in the thermal processing steps where heat-transfer treatments are involved are obviously blanching, exhausting, cooking (or "processing") and cooling. "Processing" is a term used to define the time and temperature specifications for "cooking" "sterilizing" or "retorting" any thermally processed food.

Blanching. All vegetables and a few fruits are given a hot water or steam scalding treatment known as blanching, before being placed in the containers in which they are to be processed. Its purpose is to destroy those enzyme systems which might adversely affect the quality of the product during the relatively slow rise to cooking temperature. It also acts as a cleaning operation, as it removes traces of foreign matter which might injure the flavor, drives out gas and wilts the product so that a better control of the filling operation, which it immediately precedes, is made possible. Proper blanching also reduces inside can staining in processing, particularly where exhausting is not employed. It does not materially reduce the thermal death time of resistant, spore-bearing microorganisms, as is generally believed, but it does reduce the total number of microorganisms, both mechanically by rinsing them away and biologically by destroying the less resistant types that remain.

Blanching is usually a preliminary heating in boiling water, the time varying with the product. The hardness of the water has a decided effect in the immersion method, since the first batches of the product remove most of the calcium and magnesium salts from a hard water blanching supply. Later batches will be subject to contamination from the used blanching water, especially by thermophilic bacteria and off-flavors. Consequently, it is essential that blanching water be replaced continuously in order to avoid these contaminating influences, which tend to impair quality.

There appears to be no well-established technique for blanching, as the modifications employed are almost as numerous as the canning factories using them. In the batch method, the vegetables to be preheated are placed in wire baskets and lowered into boiling water for a predetermined time. In continuous operations, the blanching method is automatically controlled by the speed of the conveying mechanism that transports the



Courtesy American Can Co.

Fig. 22.19. Typical commercial canning operations.

vegetables through the blanching machine. This may be a woven wire belt passing under and over spraying jets discharging low pressure steam or hot water; in the latter case the temperature of the water is thermostatically controlled. Where hot-water baths are used, the water overflows where the vegetables enter the machine, and the vegetables are constantly pushed forward into cleaner water. Automatic blanching machines insure uniformity of heat treatment while permitting the operation to be adjusted in conformity with the requirements for different vegetables.

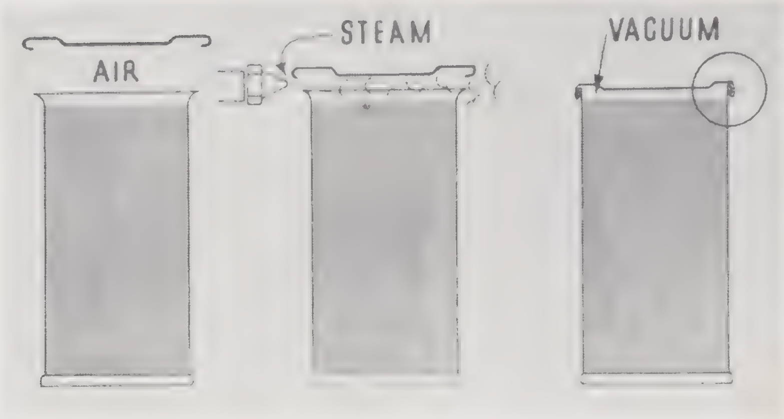
Exhausting. The term "exhausting" is often used to imply the heating of a can and its contents, whereas it actually refers to the treatments utilized to remove air and other entrapped gases, at least partially, before the cans containing their blanched contents are sealed. The incidental heating does remove gases, especially oxygen, and thus reduces can corrosion, lessens the development of oxidized flavors, and minimizes the destruction of vitamin C.

Exhausting can be performed in three ways. Normally, it is carried out at about 185 to 205°F at periods varying from 4 to 5 minutes to as high as 20 to 30 minutes, depending upon the product and whether it is packed in syrup or brine. A longer exhaust at a relatively low temperature is preferred to a shorter exhaust at a higher temperature, if only the effect and not the efficiency of the operation is considered. Heat exhausting tends to prevent overfilling of cans or glass containers, and permits a greater fill of soft products, such as berries.

High sealing temperatures insure a relatively high vacuum after processing and cooling and reduce the rate of formation of hydrogen swells. Heat-exhausting prevents undue strains on the seams of the can during the cooking operations, since cans sealed at lower temperatures develop very high pressures within the sealed can during cooking. Care must be taken, however, to govern the exhausting by the size of the cans, inasmuch as cans of No. 3 size and smaller have a vacuum of 8 to 15 inches of mercury after cooking and cooling with no apparent effects, whereas larger cans may become panelled, with the sides drawn in, or in some cases may even collapse. The less head space in the can, the greater the vacuum obtainable in the finished product.

While it is customary to exhaust by a heating method such as that described above, this can also be performed by vacuumizing the container and its contents by means of a vacuum-sealing machine, wherein the lids are spun on while the can is still in the evacuated chamber. Another method is to spin the lids in the ordinary manner, leaving a small vent hole open, which is soldered shut by an electric soldering iron in an evacuated chamber.

A third means of exhausting is by introducing a short blast of dry steam just under the lid before it is spun. This replaces the air space with live steam, which will condense after the sealing, cooking and cooling operations, and thus create a partial vacuum in the head space of the can or glass container. This practice is used extensively in glass packing for hold-



Courtesy Continental Can Co.

FIG. 22.20. Diagrammatic sketches of the steam exhausting of a filled can. At left, filled can with cover being lowered into place. Center, dry steam being used to displace air. The filled, sealed can at the right will have partial vacuum upon cooling of can and contents.

ing a close-fitting cover in place; such covers are removed by prying off to release the partial vacuum created upon cooling the contents of the bottle or glass container. This steam method of exhausting a metal can is depicted diagrammatically in Fig. 22.20.

Cooking (sterilizing, retorting or *processing).* Cooking is the most important unit operation in the canning industry. It is not sterilization in the strictest sense, for some heat-resistant aerobes or thermophiles often remain after cooking, but cannot normally develop because of unfavorable conditions. Cooking renders the product stable against bacterial spoilage. Texture, flavor and appearance of the product are improved by proper cooking; insufficient cooking permits microbial destruction of even the finest products, whereas overcooking usually reduces the grade of the product. Pressure cooking (retorting), which is used almost exclusively in the processing of most vegetables, provides the means of destroying heat-resistant organisms relatively rapidly.

The cooking temperature and time vary with the product to be processed. Products of low acidity, high protein content and containing sporogenic microorganisms are very difficult to cook properly. Vegetables, except those of high acidity, must be heated at 212°F for 3 to 10 hours to destroy spores, whereas intermittent cooking at 212°F in three periods of 1 hour each, at intervals of 24 hours, is more effective and safer than a 3-hour continuous cooking. However, even the intermittent method does not destroy *Clostridium botulinum*. In general, vegetables require more severe cooking, not only because of their low acidity, but also because of their hard texture and their proximity to soil contaminants, especially to spore-forming organisms, during growth and harvesting. Since temperatures which would spoil the color, flavor, texture and appearance of fruits in many cases improve the flavor and texture of vegetables, the latter are usually cooked at temperatures above 212°F.

The acidity of fruits, tomatoes and rhubarb lowers the thermal death time of contaminating microorganisms. As a matter of fact, fruit juices should always be processed below 212°F, the range of 150 to 185°F being more commonly used in practice, as higher temperatures injure flavor. With the exception of olives, fruits are cooked readily at 212°F for the purpose of cooking rather than sterilizing. Several meat and vegetable products are acidified to make the cooking process easier, lemon juice, vinegar, citric or tartaric acid, or some other acceptable acid often being used.

The specific heat of most fruits and vegetables differs only slightly from that of water, with the result that the error is small if it is assumed that the same amount of heat is required as would be needed to heat a similar weight of water in a like package. However, there are wide variations in their comparative rates of heat penetration. Altitude does not affect the temperature of steam cookers operating at pressures above atmospheric. The boiling point of water, however, decreases approximately 1°F for each rise of 500 feet in altitude; normally it is recommended that an additional cooking of 2 minutes be employed for each degree below 212°F.

Cooling. The cooling of cans of foods following their processing is not always given the attention it deserves, largely because its importance is either minimized or not adequately appreciated. Delay in cooling processed fruits, for example, can result in the development of dark color in peaches and pears and in the scorching and darkening of tomatoes and other vegetables. Good cooling also aids in curtailing the losses in certain vegetable packs attributable to flat sour development—a condition caused by the growth and activity of thermophilic, spore-bearing microorganisms which survive the cooking process. Rapid cooling also improves the quality of meats by preventing overcooking with its attendant undesirable effects upon flavor and texture; prevents further destruction of the gel strength; and of course reduces excessive strains on the cans themselves. Rapid cooling and cool storage are invariably beneficial to the quality of canned foods and are also the most important factors in preventing the formation of hydrogen swells.

The use of water of low bacterial count for the cooling of cans of processed foods is essential, since can seams may open slightly under the stress of sudden cooling and reclose after further cooling; thus some bacteria are entrapped, which may become the source of contamination. Chlorination of cooling-water supplies is not recommended, as it tends to increase the rusting of cans and also creates a sense of false security that tends to encourage carelessness in processing.

The cans and their contents should be cooled as quickly and as soon as possible after cooking, although care must be taken not to cool them to too low a temperature because they may remain wet and become rusty. Usually they are cooled to about 110 to 115°F, which is high enough to dry the cans but not high enough to injure the contents. Either spray cooling or immersion cooling is ordinarily practiced, both procedures requiring large amounts of water. Cooling under sprays results in more efficient use of cooling water because it takes advantage of the large amount of heat absorbed by the evaporation of the water from the can surface. This method is very successful in cooling orange juice, where extremely rapid cooling is imperative. The spent cooling water may be recooled by tower methods and reused as long as it does not become unduly contaminated.

After pressure cooking, cooling is often accomplished by introducing water into the pressure cooker; during this process it is necessary to have a counterbalancing air pressure to prevent the can from bursting as a result of too great a pressure differential between the inside of the can and the surrounding atmosphere. This external pressure drop must be simultaneously counterbalanced by an increase in air pressure or water pressure to maintain a stable pressure equilibrium within the cooker. Accordingly, at the end of the cooking period, the steam is turned off and air is introduced until the gage pressure is 2 or 3 pounds more than the processing pressure. Cold water is then admitted cautiously, and any drop in gage pressure is immediately restored with air pressure. Water is gradually added in larger amounts until the cans are covered, the gage pressure being maintained with counterbalancing air pressure. After the cans are covered with cold water, the counterbalancing air pressure is gradually released, after which the retort may be opened and the cans removed, to be further cooled by some other means. Usually the cooling process is completed by stacking the cans overnight in an area where air currents may pass freely around them to bring them to appropriate temperatures for subsequent labeling or warehousing.

Types of Heat Exchangers

The types of heat exchangers used in the thermal processing of foods are largely confined to the containers themselves and the retorts used for transferring heat through the container walls into and from the food masses. A container suitable for thermally processed foods must be: (1) rigid enough in construction to protect its contents during both thermal processing and distribution; (2) readily fabricated into convenient sizes;

(3) relatively light to permit economical handling; (4) readily opened; (5) impervious to air and water; (6) sanitary and attractive in appearance; (7) free from toxic effect on the contents; (8) capable of being heated for sterilization; (9) inexpensive, preferably cheap enough to discard after use; and (10) capable of being mechanically and hermetically sealed at high speeds. These specifications are met by both tinplate or glass. Plastic containers are finding increasing utility in food packaging, but have not as yet found any appreciable uses in thermal processing, although they may eventually be so used. Metal containers conduct heat about 30 times more rapidly than glass containers, whereas plastic containers generally are themselves adversely affected by high temperatures.

Water is a very poor conductor of heat when convection is prevented, being only about 25 per cent as rapid as glass. This explains why some foods containing large amounts of water heat and cool slowly. Since the water in these instances is not free to circulate, conduction is the only means of heat transfer. In this case the rate is slow and the composition of the container has little effect. It has been demonstrated that there is very little difference between the heating times of meats potted in tin and in glass; pumpkin, potatoes, sliced apples and spinach are examples of other food products with similar heat penetration characteristics. If the water in the pack is free to circulate, the heat is transferred by convection, and heat penetration will occur as rapidly as is permitted by the container and the degree of agitation of its contents. Nevertheless, glass containers normally take twice as long as those of tin plate of the same capacity in heating and cooling peas and beans, for example, surrounded by free-flowing liquid where the heat is transferred by convection. The rate of heat conductance [Btu/(hr) (°F)] for water is about 0.084, for glass 0.37, and for iron 10.8, which indicates that tin plate might be expected to transfer heat by conductance probably 120 times faster than water. It should be pointed out, however, that this comparison fails to recognize the importance of turbulent water films in expediting heat transfer.

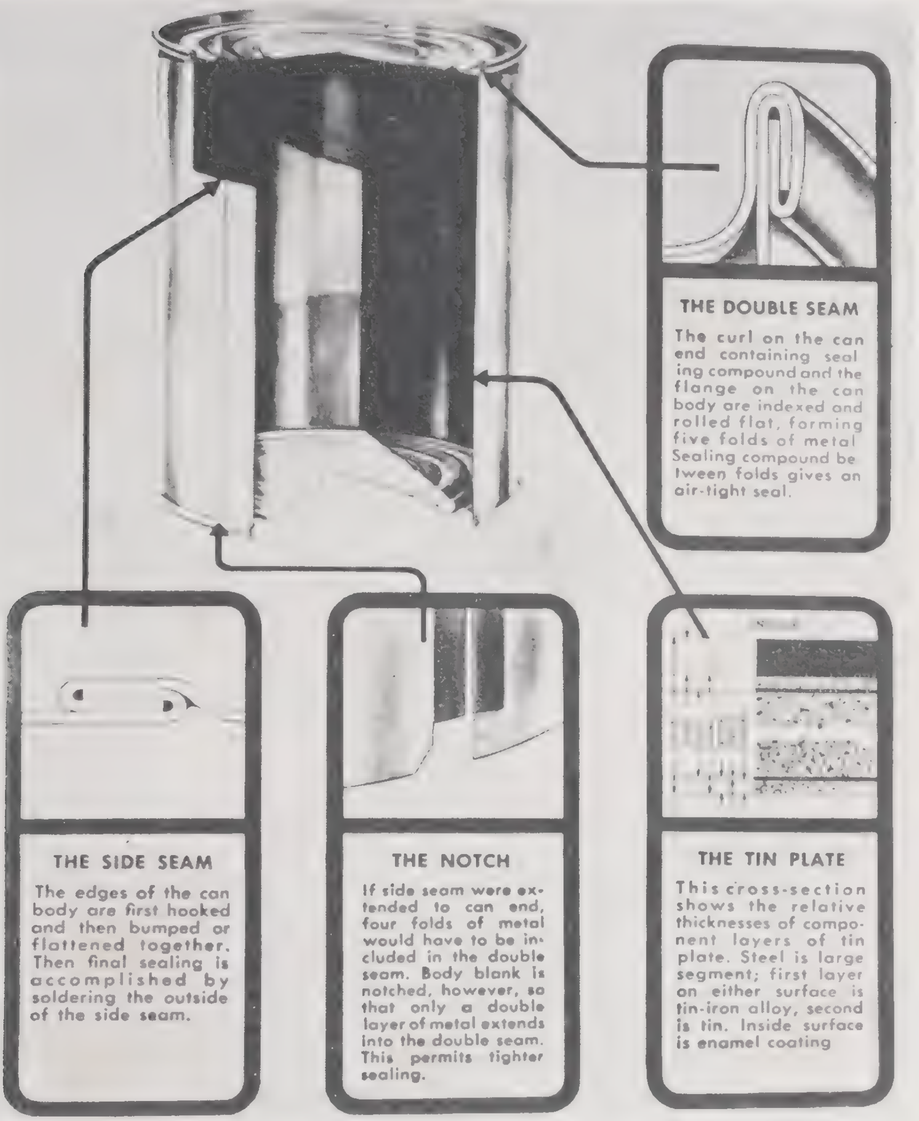
Tin Cans. Although the earliest canning (as we call it today) was done in glass, tin-plated cannisters which are actually steel plate coated with thin veneers of tin plate, have come to occupy an extremely important place both in modern processing and distribution of foods. While we commonly refer to these metal food containers as "tin cans," we are almost daily depending less and less on tin-plate for resistance to corrosion and reaction with foods, as it is rapidly being supplemented or replaced by various types of lacquers and enamels.

Before World War II, the generally accepted minimum weight of tin applied by the hot-dip method was 1¼ pounds per base box (a base box is that quantity of steelplate known as "tin plate" which has an area of approximately 31,360 square inches and a variable weight generally in the neighborhood of 100 pounds). Now, however, a base plate is generally coated with from one-quarter to one-half pound of electrolytically plated tin. Two major types of enamels or lacquers are used: "sanitary" (also known as "R" or fruit enamel) and "C" enamel, used largely to prevent staining of the tin plate as well as discolration of sulfur-bearing foods of the low-acid type. The "R" enamel is used primarily to prevent color loss in pigmented fruits or colored vegetables which have a water-soluble pigment.

The tin can, therefore, is the most efficient heat exchanger in affecting the transfer of heat in the thermal processing of foods. Cans are available in a wide variety of sizes and in several different shapes, all of which have important bearing upon the rates of heat transfer within its contents, although the contents themselves offer by far the greatest resistance. Practically the only factor the tin can itself introduces is the ratio of its heat transfer surface to the mass and volume of its contents. In an effort to avoid the confusion arising from the conflicting local names given to different can sizes, there has developed a system of nomenclature within the industry by which the approximate dimensions of a can are identified by numbers of three digits. The first number given indicates the diameter of the can, and the second specifies its height. The first digit gives the number of whole inches and the next two digits the additional fraction of an inch in sixteenths. Thus the common No. 2 can is referred to as a 307 x 409, which means that the diameter and height are approximately $3^7/_{16}$ inches and $4^9/_{16}$ inches, respectively. Fig. 22.21 shows the construction detail of an enameled sanitary-type tin can.

Glass Containers. Although most thermally processed foods are packed in tin cans, a considerable quantity is packed in glass containers. Actually, glass is not a substitute for cans, but an alternate container, whose chief advantages are its chemical inertness and insolubility and its considerable virtue of transparency. These properties are somewhat offset by the necessity for greater care in handling, although even this has been minimized by the development of glass with high resistance to mechanical and thermal shock. However, glass increases shipping weights and requires a relatively greater amount of manpower for comparable volume of production. While available in a great variety of shapes and colors with a number of different closures, glass containers are definitely not as suitable for heat transfer as metal cans. Most of the heat-processed, glass-packed foods are sealed with a metal cap which carries a gasket and protective circle or lining that insures hermetic sealing.

Retorts. These are closed pressure-type vessels using steam from some



THE DOUBLE SEAM

The curl on the can end containing sealing compound and the flange on the can body are indexed and rolled flat, forming five folds of metal. Sealing compound between folds gives an air-tight seal.

THE SIDE SEAM

The edges of the can body are first hooked and then bumped or flattened together. Then final sealing is accomplished by soldering the outside of the side seam.

THE NOTCH

If side seam were extended to can end, four folds of metal would have to be included in the double seam. Body blank is notched, however, so that only a double layer of metal extends into the double seam. This permits tighter sealing.

THE TIN PLATE

This cross-section shows the relative thicknesses of component layers of tin plate. Steel is large segment; first layer on either surface is tin-iron alloy, second is tin. Inside surface is enamel coating

Courtesy American Can Co.

FIG. 22.21. Details of metal can construction.

outside source, such as steam boilers or steam generators. Thermal processing, as we have already stated, is the most important unit operation in the canning industry. Thermal processing is, in fact, just another name for retort operation. If suitable equipment is not provided and properly operated by competent personnel, the operation can result in appreciable product losses, even to the extent of the financial failure of a business enterprise. To obtain maximum benefits, retorts should be properly installed and have an adequate steam supply. All installations must comply with local codes with respect to piping and necessary safety devices. The type and sizes of retorts vary considerably, as do the individual installations.

Retorts of the stationary type may be either vertical or horizontal, and are constructed for various maximum working pressures. Standard construction is for 15 psi maximum operating pressure; for higher pressures, special construction is necessary. The 42-inch diameter vertical three-crate retort is the most common type, although the four-crate unit is used extensively where cook room space is limited. Horizontal retorts vary over wide limits as to size, some being round, some square, with doors at one or both ends. The vertical units are more efficient with respect to the number of cans they will hold per unit of retort volume. They also occupy less floor space for a given can capacity than do the horizontal types; however, more mechanical handling of the crates is necessary. On the other hand, horizontal retorts can be made larger than vertical and carts, dollies or conveying systems can be used to facilitate the incidental materials handling problems of loading and unloading.

In estimating the number of retorts required for a given operation, the following information is essential:

(1) Determine the retort cycle by totalling all the following measured in minutes:
  (a) Retort come-up time
  (b) Process time
  (c) Loading time
  (d) Unloading time

(2) Estimate the number of cans closed per minute (closing machine speed).

(3) Determine the retort capacity of one retort for a selected can size. Tables 22.3 and 22.4 indicate the number of cans per retort for various can sizes for standard vertical three- and four-crate retorts. Due to the variations in size of carts used, no tables of cart capacity are practical for horizontal retorts. However, in the subsequent calculations if the capacities for horizontal retorts are known the procedure will be the same as for vertical retorts.

The number of retorts required can be determined with the following formula:

$$N = \frac{C \times R}{H}$$

where N = number of retorts required,
C = retort cycle in minutes,
R = speed of closing machine in cans per minute,
H = number of cans which one retort will hold.

Table 22.3*. Number of Cans Per Retort
(Vertical Retorts—Cans Stacked on End)

Can Size	Approximate No. Cans per Retort 3-Crate	Approximate No. Cans per Retort 4-Crate
211 x 109	6250	8330
200	4310	5750
212	3360	4480
300	2880	3840
400–414	1920	2560
600	1440	1920
300 x 108	4470	5970
206	2720	3630
308	1710	2280
400–411	1370	1820
509	1030	1370
303 x 406	1820	2420
509	910	1210
307 x 203	2590	3450
306	1440	1920
400–409	1150	1330
510	860	1150
401 x 411	730	970
404 x 307	820	1100
414	660	880
700	330	440
603 x 700	190	240
(Standard) (Crate)	(Top Crate 3 layers)	(Top Crate 3 layers)
	160	160
	(Cans on side)	(Cans on side)
603 x 700	240	320
(No. 10) (Crate)		
	160	160
	(Cans on side)	(Cans on side)

* Source: Bull. No. 19, Research Dept. Continental Can Co., 1950.

Frequently, the number of retorts as determined by this formula will contain a fraction. In those cases where the fraction is 0.4 or less, the next higher number will be the proper number of retorts to recommend; when the fraction is 0.5 or greater, the next whole number *plus one* is the number of retorts to be recommended. Such recommendations are based upon the extensive experience of those familiar with retort operations[24].

For best results, it has been repeatedly demonstrated that steam at 100 to 125 psi line pressure should be available for operating retorts. In expressing rates of steam flow, the term "boiler horsepower" is used. One boiler horsepower is that amount of steam equivalent to 33,480 Btu per

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[24] For full details, consult Bulletin No. 19, Research Department, Continental Can Company, 1950.

TABLE 22.4*. NUMBER OF CANS PER RETORT
(Vertical Retorts—Cans Scrambled)

Can Size	Approximate No. Cans per Retort 3-Crate	Approximate No. Cans per Retort 4-Crate
12 oz. oblong	1120	1500
202 x 214	3000	4000
211 x 109	4700	6200
200	3200	4300
212	2500	3300
300	2150	2900
400	1500	1950
414	1450	1900
600	1080	1400
300 x 108	3300	4500
206	2000	2700
400–411	1050	1400
509	760	1000
303 x 406	1350	1800
509	680	900
307 x 203	1980	2590
306	1080	1440
400	900	1200
409	850	1140
510	650	850

* Source: Bull, No. 19 Research Dept., Continental Can Co., 1950.

hour, which if produced or consumed in one hour would condense to approximately 34½ pounds of water at 212°F. The peak consumption of steam for standard vertical retorts or a horizontal unit of similar volume will vary from 80 to 200 boiler horsepower per hour for steam inlets of 1- to 2-inch pipe sizes. Since the peak demand of 80 to 200 hp exists for only a relatively short time, the total amount of steam consumed is not likely to be so great. For processes up to 60 minutes, a total of approximately 300 pounds of steam is consumed, and about half this amount is used during the venting operation. After the vent valve is closed and the retort reaches operating temperature, the consumption rate decreases rapidly to around 3 to 5 horsepower and remains at this rate for the balance of the process. Steam-generating systems should be sized so shat an adequate steam supply over and above that required for other operations will be available for retorting. In Table 22.5 are listed the properties of saturated steam.

Discontinuous Nonagitating Pressure Cookers. Temperatures of 240°F or higher are readily obtainable in such cookers. The simplest form consists of the upright heavy steel cylinder which is heated by steam, as illustrated in Fig. 22.22. The vertical cooker depicted, which is sunk to below floor level, is more popular in the East, while the horizontal type is more common in

TABLE 22.5*. PROPERTIES OF SATURATED STEAM

Pressure				Enthalpy (Btu per lb)		
Absolute (psi)	Absolute (in. Hg)	Temp. (°F)	Volume Steam (cu ft per lb) V_g	Sat. Liquid h_f	Evap. Latent Heat h_{fg}	Sat. Vapor h_g
5	10.2	162.2	73.5	130.1	1001.0	1131.1
6	12.2	170.1	62.0	138.0	996.2	1134.2
7	14.2	176.8	53.6	144.8	992.1	1136.9
8	16.3	182.9	47.3	150.8	988.5	1139.3
9	18.3	188.3	42.4	156.2	985.2	1141.4
10	20.4	193.2	38.4	161.2	982.1	1143.3
11	22.4	197.7	35.1	165.7	979.3	1145.0
12	24.4	202.0	32.4	170.0	976.6	1146.6
13	26.4	205.9	30.1	173.9	974.2	1148.1
14	28.5	209.6	28.0	177.6	971.9	1149.5
14.7	29.9	212.0	26.8	180.1	970.3	1150.4
	Approx. Gage (psi)					
15	0	213.0	26.3	181.1	969.7	1150.8
20	5	228.0	20.1	196.2	960.1	1156.3
25	10	240.1	16.3	208.4	952.1	1160.6
30	15	250.3	13.7	218.8	945.3	1164.1
35	20	259.3	11.9	227.9	939.2	1167.1
40	25	267.2	10.5	236.0	933.7	1169.7
45	30	274.4	9.40	243.4	928.6	1172.0
50	35	281.0	8.51	250.1	924.0	1174.1
55	40	287.1	7.79	256.3	919.6	1175.9
60	45	292.7	7.17	262.1	915.5	1177.6
65	50	298.0	6.65	267.5	911.6	1179.1
70	55	302.9	6.21	272.6	907.9	1180.6
75	60	307.6	5.82	277.4	904.5	1181.9
80	65	312.0	5.47	282.0	901.1	1183.1
85	70	316.2	5.17	286.4	897.8	1184.2
90	75	320.3	4.90	290.6	894.7	1185.3
95	80	324.1	4.65	294.6	891.7	1186.2
100	85	327.8	4.43	298.4	888.8	1187.2
105	90	331.4	4.23	302.1	886.0	1188.1
110	95	334.8	4.05	305.7	883.2	1188.9
115	100	338.1	3.88	309.1	880.6	1189.7
120	105	341.2	3.73	312.4	877.9	1190.4
125	110	344.3	3.59	315.7	875.4	1191.1
130	115	347.3	3.45	318.8	872.9	1191.7
135	120	350.2	3.33	321.8	870.6	1192.4
140	125	353.0	3.22	324.8	868.2	1193.0
145	130	355.8	3.11	327.7	865.8	1193.5
150	135	358.4	3.01	330.5	863.6	1194.1
160	145	363.5	2.83	335.9	859.2	1195.1
170	155	368.4	2.67	341.1	854.9	1196.0
180	165	373.1	2.53	346.0	850.8	1196.9
190	175	377.5	2.40	350.8	846.8	1197.6
200	185	381.8	2.29	355.4	843.0	1198.4
215	200	387.9	2.13	361.9	837.4	1199.3

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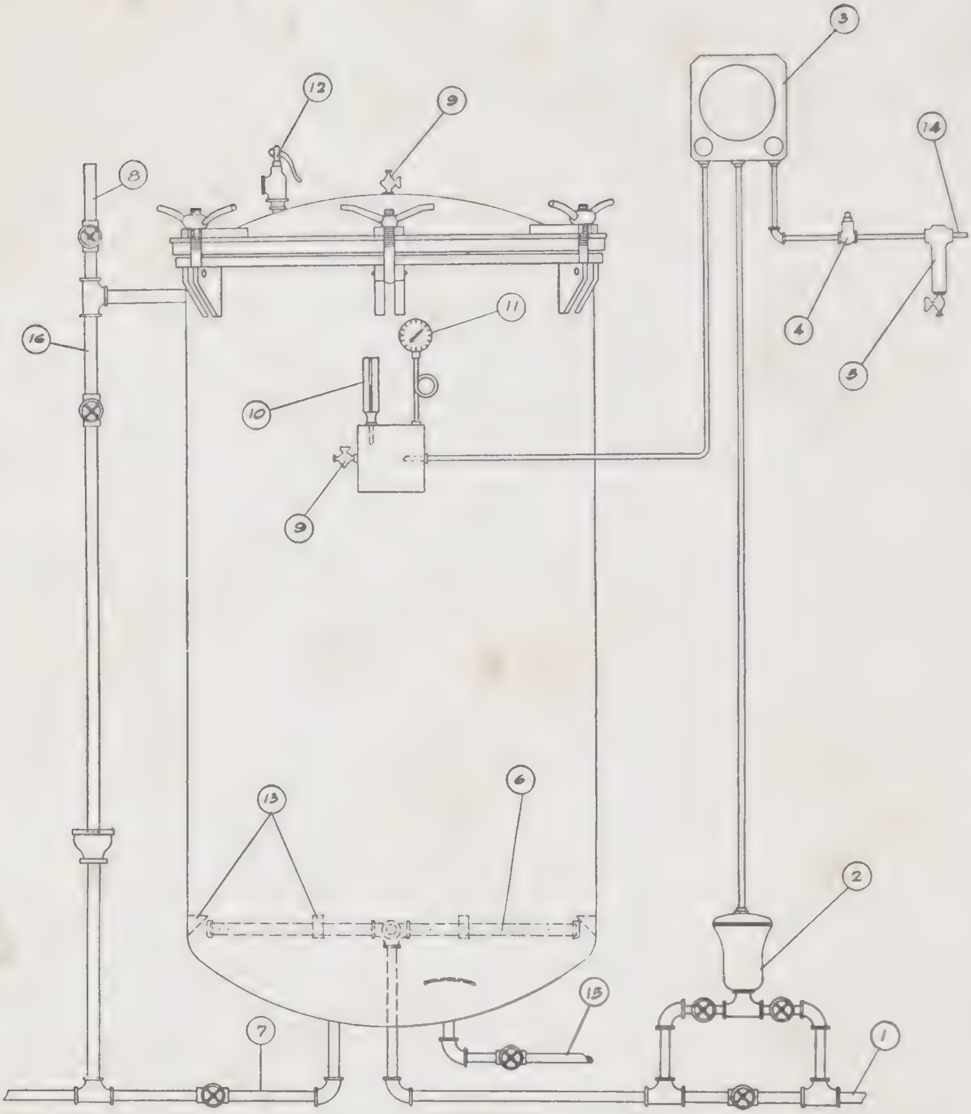
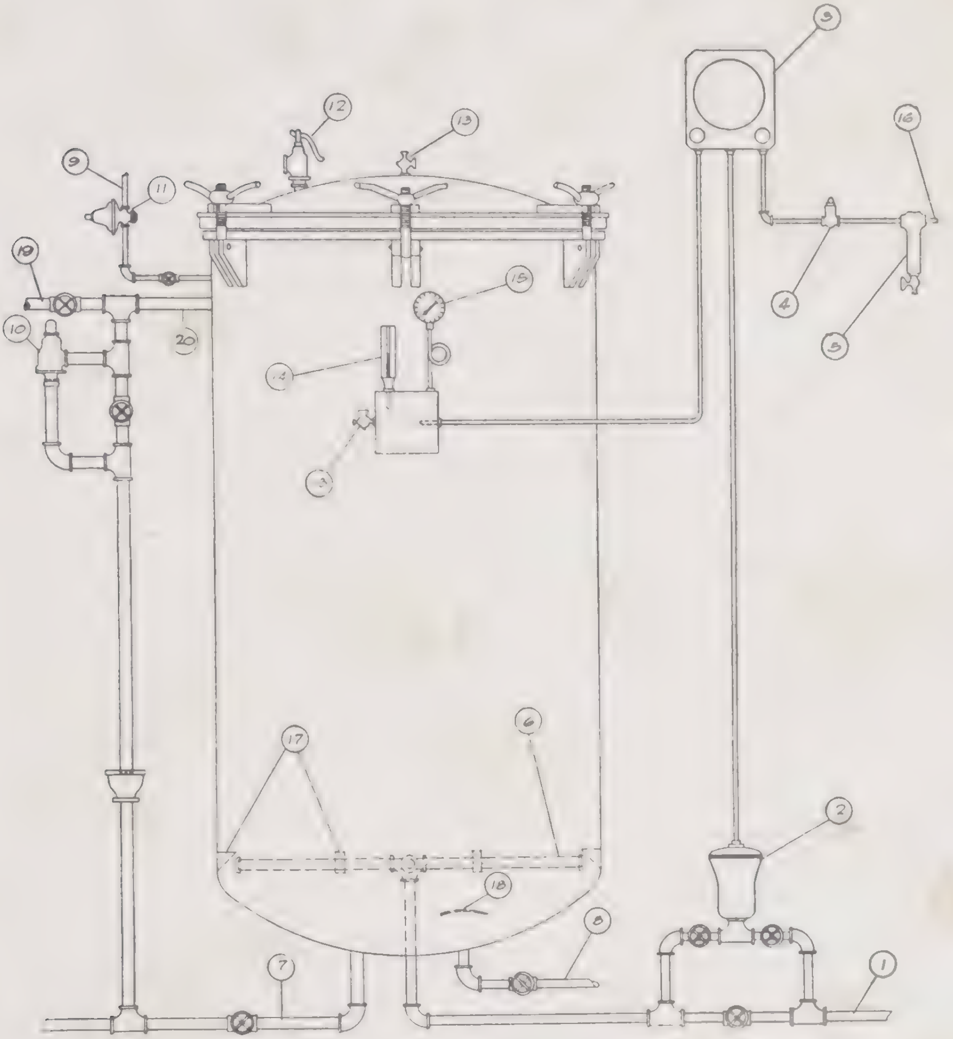
* Source: "The Votator Book," 1949. (Abstracted by permission from "Thermodynamic Properties of Steam" by J. H. Keenan and F. G. Keyes, published by John Wiley & Sons, Inc.)



Courtesy Continental Can Co.

FIG. 22.22. Simple processing with vertical pressure cooker. (1) steam, (2) regulating valve, (3) controller, (4) reducing valve, air, (5) air filter, (6) steam distributor, (7) drain, (8) vent, (9) bleeders, (10) indicating thermometer, (11) pressure gage, (12) pop safety valve, (13) basket supports, (14) air for controller, (15) water, (16) overflow, ⊕ manual valves.

the West. Upright pressure cookers are usually operated in batteries above which a traveling crane is available to facilitate loading and unloading the retorts. Cans are placed in circular crates and lowered into the cookers, which are usually small. Since only a few cans are required to fill this type of cooker, the exhausted or sealed cans do not have an opportunity to cool appreciably before cooking. This same type of vertical cooke



Courtesy Continental Can Co.

Fig. 22.23. Pressure cooling under air pressure. (1) steam, (2) regulating valve, (3) controller, (4) reducing valve, air, (5) air filter, (6) steam distributor, (7) drain, (8) water, (9) air, (10) pressure relief valve, (11) reducing valve or controller, (12) safety pop valve, (13) bleeders, (14) indicating thermometer, (15) pressure gage, (16) air for controller, (17) basket supports, (18) water inlet bafflle, (19) vent, (20) overflow, ⊕ manual valves.

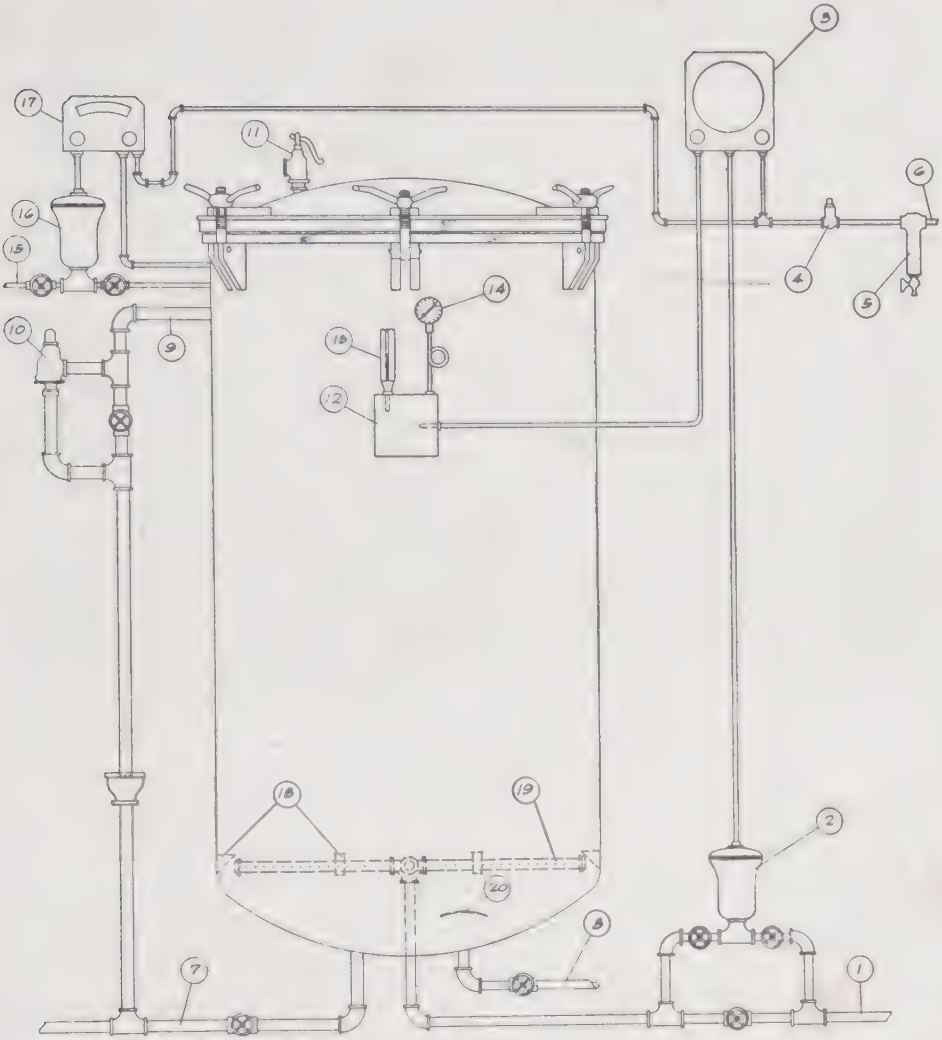
can also be utilized for pressure cooling under air pressure, as illustrated in Fig. 22.23.

It is usually desirable and often necessary to process cans having large areas of flat surface in superheated water and with superimposed air pressure. Retort hook-up for this procedure is practically the same as for pressure-cooling with air. The water temperature is controlled by a temperature regulator to admit steam for heating, and a separate control system is used for controlling the superimposed air pressure. A source of hot water for filling the retort is advisable in order to reduce come-up time. Insulated storage tanks for hot water are often used, with pumps for transferring water to and from the retorts. A supply of compressed air capable of maintaining pressures up to 30 psi in the retort is usually required. This type of retort installation permits processing in either metal cans or glass containers and can be equally satisfactory for cooking and cooling the load of containers being processed. The proper installation of a retort equipped for water processing with superimposed air pressure is illustrated in Fig. 22.24.

Discontinuous Agitating Pressure Cookers. This type of pressure cooker was developed especially for the dairy industry in the sterilization of milk, because of its tendency to scorch and curdle unless thoroughly agitated during cooking under pressure. It is oftentimes necessary to fortify milk with sodium citrate or sodium phosphate to maintain a proper salt balance, and this is also a factor in curdling. Indeed, most milk processors are equipped with pilot installations which they use to determine the amounts or charges of citrate needed to prevent curdling. In the agitating retorts used to keep milk properly mixed, the cans are placed in a cage within the cooker, and the cage is revolved so that the cans are constantly in motion during the cooking. This results in an end-over-end type of agitation within the cans. The usual size of the retorts or cookers is approximately 5 feet in diameter and 10 to 20 feet in length. They are the forerunners of the end-over-end agitating retorts now being increasingly used in thermal processing of canned foods.

An interesting type of discontinuous agitating pressure retort has recently been developed which incorporates in its design the principles of end-over-end agitation discussed in Chapter 21. Cans are placed in portable baskets which, in turn, slide into pockets in the reel of the machine (see Fig. 22.25). The door of the retort is then closed and retorting proceeds, the reel rotating its peripheral load of cans at the proper rpm and at the appropriate processing conditions. Higher processing temperatures are possible because of the agitation of the milk produced by the end-over-end action, and consequently the processing time is greatly reduced. Cooling is similarly expedited. This type of agitating retort is now being redesigned to provide fully automatic, continuous operation.

Automatic Pressure Cookers. The thermal processing of vegetables and meats involves use of several types of automatic pressure cookers. The *continuous* cooker takes round cans only and consists of a horizontal steel cylinder capable of withstanding the necessary pressure. Inside the cylinder are a reel and spiral which permit the cans to roll on their sides while

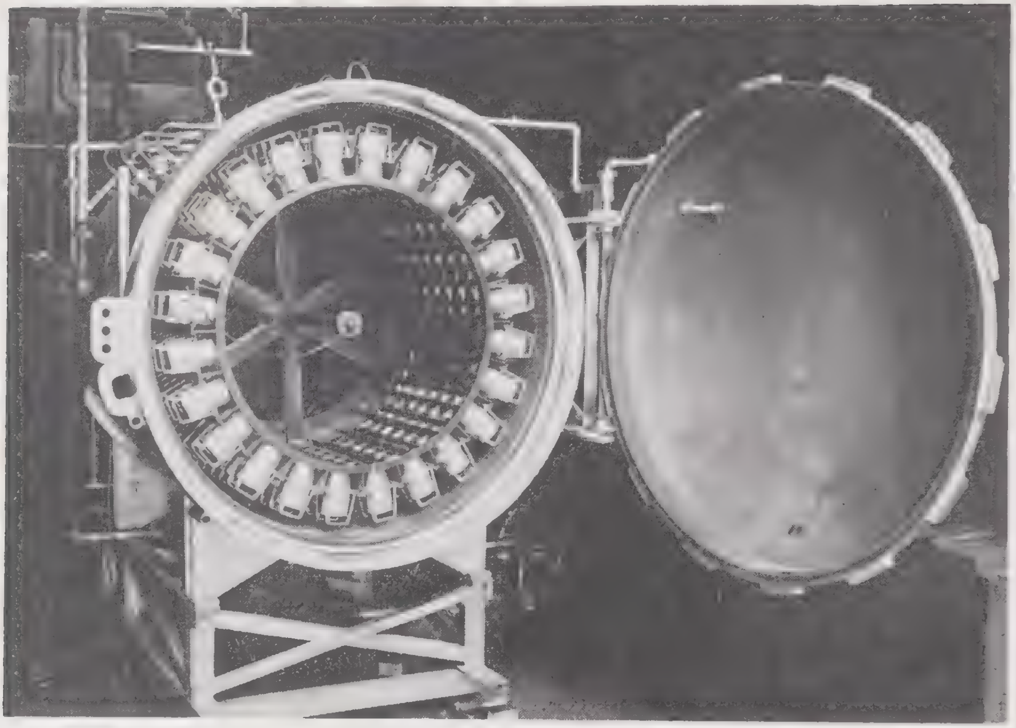


Courtesy Continental Can Co.

Fig. 22.24. Water process with superimposed air pressure. (1) steam, (2) regulating valve, (3) temperature controler, (4) reducing valve, (5) air filter, (6) air, (7) drain, (8) water, (9) overflow, (10) pressure relief valve, (11) pop safety valve, (12) patch type well, (13) indicating thermometer, (14) pressure gage, (15) air, (16) regulating valve, (17) pressure controller, (18) basket supports, (19) steam distributor, (20) water inlet baffle, ⊕ manual valves.

being propelled toward the discharge end of the machine; the rotation of the reel is adjusted to the speed necessary to subject the can to the proper conditions of time and temperature. A special valve allows cans to enter and leave the cooker without the pressure in the latter being affected.

The principal difficulties with continuous agitating cookers result from releases of pressure as cans enter and leave the cooker. Their main ad-



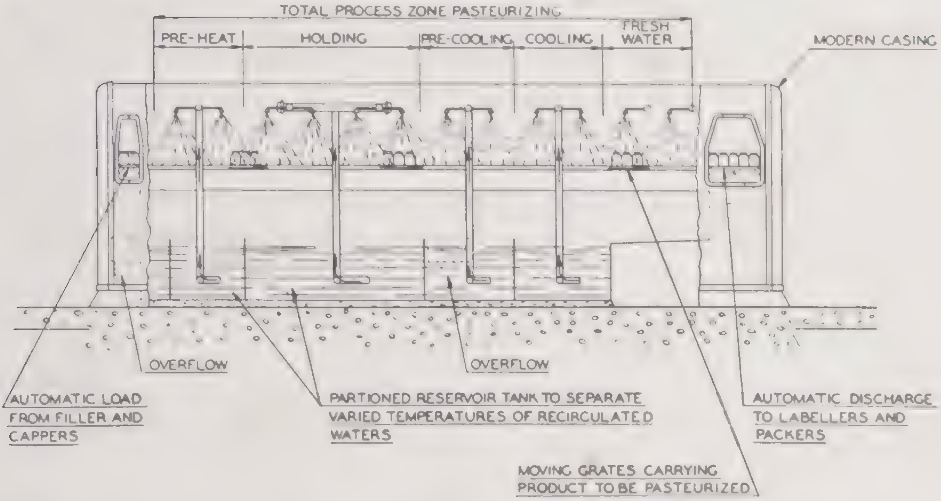
Courtesy Chain Belt Co.

FIG. 22.25. End view of opened Agi-Tort end-over-end agitating steam retort for processing canned foods.

vantage is that a much higher temperature may be used, permitting a greatly reduced cooking time, because the agitation avoids overheating of the product in contact with the container. As discussed in Chapter 21, agitation increases the rate of heating and cooling; hence a shorter overall time of processing is made possible. The present great disadvantage lies in its high initial cost. An especially effective continuous cooker has been designed and is presently operating in various localities for canning cream style corn.

Open cookers are still used by some small canneries and to a limited extent by large canneries for small miscellaneous lots of fruit. This term may be confusing, as it refers to equipment utilized for cooking at atmospheric pressure at approximately 212°F. These cookers, although almost completely enclosed, are not designed to withstand the pressure conditions incidental to the construction of steam-pressure retorts.

Another type of atmospheric heat exchanger consists basically of an enclosed cabinet equipped with a moving conveyor and a series of overhead sprays of tempered water; appropriate temperature adjustments provide for the pasteurization and heat-processing of foods primarily in glass containers. This equipment can be used for exhausting, pasteurizing


TOTAL PROCESS ZONE PASTEURIZING
PRE-HEAT
HOLDING
PRE-COOLING
COOLING
FRESH WATER
MODERN CASING
OVERFLOW
OVERFLOW
AUTOMATIC LOAD FROM FILLER AND CAPPERS
PARTIONED RESERVOIR TANK TO SEPARATE VARIED TEMPERATURES OF RECIRCULATED WATERS
AUTOMATIC DISCHARGE TO LABELLERS AND PACKERS
MOVING GRATES CARRYING PRODUCT TO BE PASTEURIZED

Courtesy Barry-Wehmiller Machinery Co.

FIG. 22.26. Diagram of pasteurizing system of atmospheric heat exchanger. By proper adjustment of belt conveyor this exchanger can be converted into a cooling or a steam-exhausting system.

or cooling with equal facility by proper adjustment of the conveyer belt speed and temperatures of sprays using either steam or water (see Fig. 22.26).

HEATING BY RADIATION

The third method of heating is by radiation, that is, a transfer of energy in the form of electromagnetic waves, which travel in straight lines at the speed of light. The sun emits radiant energy, which travels through space and the atmosphere and reaches the earth, where it is absorbed. All substances which absorb radiation also are capable of emitting energy as electromagnetic waves.

The radiant energy impinging upon a body is either absorbed, reflected, or transmitted through the body. Materials which absorb all the incident energy are called *black bodies*. Although no real surface behaves as a true black body, it is a useful reference for comparison. The best example of a black body is a small hole in a large empty container. All the radiant energy entering the hole is absorbed by the inner walls of the container, either on first contact or by subsequent contacts after continued reflection within the interior. In general, the quantity of heat radiated is proportional to the fourth power of the absolute temperature and inversely proportional to the distance from an object. Black bodies absorb radiant energy most efficiently, and polished surfaces absorb the least.

The general equation covering radiation of heat from small bodies surrounded by a large body is as follows:

$$H = APC\left[\left(\frac{T_1}{100}\right)^4 - \left(\frac{T_2}{100}\right)^4\right] \tag{8}$$

where H = Btu/(hr) (sq ft),
A = area of hot body in sq ft,
P = percentage blackness of small hot object (usually 90% for unpolished metals),
C = a constant = 0.172 Btu/(hr)(sq ft) $(\text{degrees absolute}/100)^4$,
T_1 = absolute temperature of hot body,
T_2 = absolute temperature of cold body.

Modifications and additions of the above equation are needed to cover special conditions.*

In practice, when a hot body of small size is exposed to a cooler gas, heat is lost both by radiation and convection. A simplified formula, using radiation constants which may be found in various heat-transfer reference sources, will give reasonably accurate results. With these data, the heat loss from pipes can be readily calculated and will be found useful in the design of drying equipment, etc.:

$$\text{Btu loss} = t \times K \times A \times (T_1 - T_2) \tag{9}$$

where t = time in hours,
K = radiation and convection constant,
A = pipe area = pipe diameter × 3.1416 × pipe length (ft),
T_1 = pipe temperature in °F,
T_2 = ambient air temperature in °F.

In most cases where radiant energy is utilized in heat-transfer applications in food processing, such as roasting, baking, drying, etc., the actual transfer of heat includes both radiation and convection. Computations are usually best made by determining the heat transferred by both methods and adding the two quantities. In many cases, however, it is convenient to compute the rate of heat transfer by radiation according to the same equation used for convection transfer; this may be done by combining equations to solve for the radiant heat transfer coefficient, which is expressed as Btu (hr) (sq ft) (°F) as a function of black bodies T_1 and T_2.

Roasting and toasting provide the best examples of the use of radiant energy in food processing. They are usually applied to nuts and beans of various sorts, as well as to certain breakfast cereals, such as corn flakes, to develop a desired flavor rather than to effect sterilization. Obviously the temperatures which roasted or toasted products attain are high enough to destroy enzyme systems, molds, yeasts, and probably most contaminating bacteria. Since such operations are customarily carried out with dry heat, a considerable amount of moisture is also removed, which has the advantage of producing crispness (due to loss of moisture), as well as desirable flavors. The methods and results achieved vary with each product; consequently the types of roasters in general use are almost as numerous as the products.

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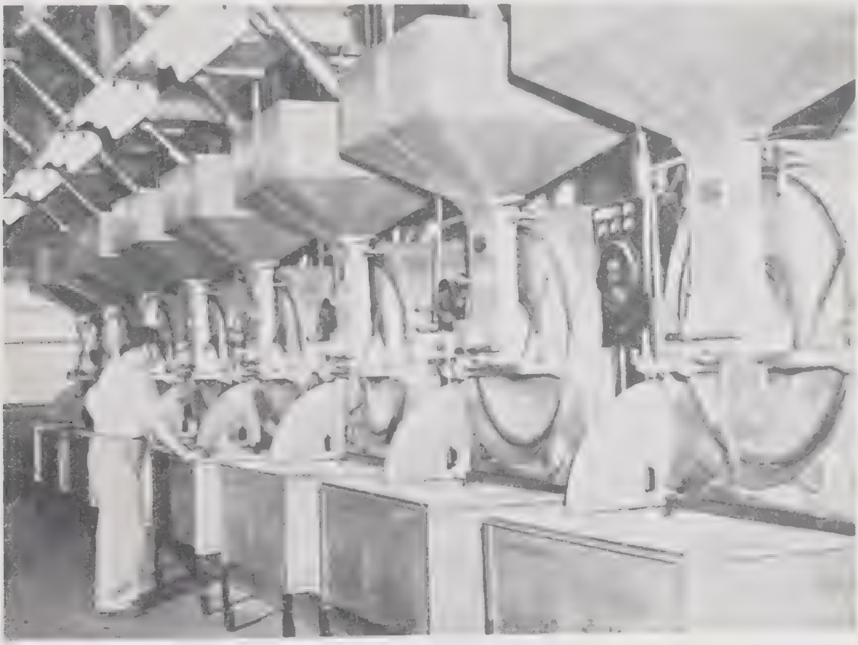
* See Unit Operations by G. G. Brown & Associates, John Wiley & Sons, Inc., 1950.

Types of Heat Exchangers

Hot Air Roasters. These are the most efficient types. The product is fed into a hopper and then passed into cylindrical vessel. Air is passed through a gas or vaporized fuel-oil heater and blown directly upon the product, which is kept in constant motion by rotation of the cylindrical ovens or containers. The fumes from the burning dust and fragments of various extraneous materials are removed by the hot air, thus preventing development of foreign and crude flavors. This type of machine is capable of being rapidly charged and discharged by simple operation of the appropriate slide valves. The duration of the roasting period varies with the size of the charge and degree of roasting desired, a charge of 300 pounds normally requiring 30 to 40 minutes for a medium roast.

Cooling devices such as perforated pans equipped with rotating rakes and air suction to facilitate rapid cooling of the roasted beans or nuts is illus-



Courtesy Bauer Bros. Co.

FIG. 22.27. Battery of eight radiant roasters equipped with color controllers

trated in Fig. 12.9 (Volume I). Indicating and recording thermometers are utilized to control both roasting and cooling operations.

Direct Heat Roasters. Most common is a rotating cylinder having a capacity of 100 to 200 pounds, heated by a series of gas jets impinging upon the outer surface of the cylinder. Forced air draft is provided with the proper air-circulating fans. The product is placed in a hopper mounted on top of the cylinder and then fed into the cylinder by means of a slide or chute. After the cylinders are set in motion, the gas jets are ignited. As the temperature rises, the moisture comes off as steam and escapes from the sides of the roaster. A small hole in the center of the cylinder permits insertion of a thermometer and removal of samples during roasting. The main disadvantages of this type of roaster are (1) breaking of brittle products during roasting, and (2) smoky flavor due to charring of portions of the product.

Radiant Roasters. These are not used widely, but are finding increasing favor where fine temperature and time control are desired for small batches of "flavor" beans. They are costly as far as power is concerned, but time and space are conserved. The interior of the bean is roasted more evenly and some units are equipped to shut off when the bean reaches some predetermined temperature; others are now utilizing automatic devices known as "color controllers" (see Fig. 22.27). The radiant heat for these roasters is developed by special burners using natural or manufactured gas or vaporized fuel oil. These provide uniform heat and therefore uniform color penetration through nuts, beans, seeds and other products, while leaving the surfaces comparatively dry of any rendered oil.

Toasters. Corn grits, or hominy, after being properly processed to form flakes, are spouted as directly as possible to either rotary or flight-type ovens for toasting. The ovens are usually gas-fired and consist of a slightly conical, cylindrical, rotating, fine perforated metal screen about 4 feet in diameter and 20 feet long enclosed in a well-insulated outer jacket or housing, which is exhausted to the atmosphere for the removal of moisture and fumes. By close control of the temperature and moisture conditions, a bubbly appearance can be produced in the finished flakes. The properly toasted flakes are carried to a screening and cooling device for the removal of broken flakes and cooling, and then are directed to the packing bins.

23. *Heat Exchanging*

II. Refrigerating Applications

Heat loss, or "cold penetration," is obviously the reverse of heat gain, or heat penetration. Withdrawal of heat from a body as a heat exchanging unit operation is commonly referred to as *refrigeration*, especially when freezing and subfreezing temperatures are attained.

Whereas heating a food product to medium or high temperatures tends to inactivate or destroy spoilage factors, refrigerating contributes to food preservation by materially retarding them, and at temperatures below freezing, the possibility of spoilage is greatly reduced. However, freezing itself causes marked changes in many foods and is the accidental cause of spoilage of some fresh foods such as fruits and vegetables. Nevertheless, it can be stated that in general, refrigerating foods at commercial cold storage temperatures and humidities does not stop deterioration of perishable foods, although it does markedly retard it. As a rule, the lower the temperature the slower the deterioration, although there are many exceptions to this generality.

Heat loss rates vary with the nature of the product, yet the differences are much less than those observed in heat penetration. The temperature differential between the product and the surrounding refrigerating medium governs the rate of heat loss; yet the differential is much less than in heat penetration rates. In fact, the rates of heat loss are governed by the same laws with but one exception: *as a product starts to freeze, heat is removed from it by conduction only.* As might be expected, ice formation first occurs at the product-refrigerating medium interface, the ice so formed slowly conducting heat away from the center to the refrigerating medium. In other words, refrigeration always involves heat transfer *away* from a warm body to a cooler one, and so continues until an equilibrium is established with the two bodies at the same temperature.

Types of Refrigeration

There are two principal types of refrigeration—natural and artificial. Natural refrigeration utilizes ice water, water ice, or ice-and-salt mixtures, whereas artificial refrigeration requires refrigerating machinery.

Natural Refrigeration. Cooling by ice is an old process and is effective because as ice melts, it absorbs great quantities of heat before the temperature changes. One pound of ice in melting, absorbs 144 Btu of heat—its latent heat of fusion. This means, of course, that a ton of ice in melting will absorb 2,000 times as much, or 288,000 Btu. Furthermore, a pound of ice at 0°F in warming up to 32°F will absorb 0.5 Btu per degree rise in temperature, or 16 Btu. When 32°F is reached, the temperature will not rise further until the ice absorbs 144 Btu more, after which the water will absorb 1 Btu per pound for every degree of temperature rise. It is frequently

TABLE 23.1*. PROPERTIES OF BRINES

Lb NaCl or Ca Cl in 100 lb Solution (Wt. %)	Sp. Gr. (60°/60°F)	Degrees Baumé (60°F)	Freezing Point (°F)	Corresponding Ammonia Back Pressure (psi gage)	Specific Heat at			
			Pure Sodium Chloride Brine					
					14°F	32°F	50°F	68°F
6	1.044	6.06	25.5	39.6	.....	0.924	0.927	0.929
8	1.058	8.00	22.9	36.7	.....	0.902	0.906	0.909
10	1.073	9.91	20.2	33.7	.....	0.882	0.887	0.890
12	1.088	11.78	17.3	30.7	.....	0.865	0.869	0.873
14	1.104	13.63	14.1	27.6	.....	0.848	0.853	0.857
16	1.119	15.45	10.6	24.3	0.827	0.834	0.839	0.842
18	1.135	17.25	6.7	21.0	0.815	0.821	0.825	0.828
20	1.151	19.02	2.4	17.5	0.804	0.809	0.813	0.815
22	1.167	20.78	−2.5	14.0	0.794	0.798	0.801	0.803
24	1.184	22.51	+1.4	16.8	0.784	0.788	0.791	0.792
			Pure Calcium Chloride Brine					
					−4°F	14°F	32°F	50°F
6	1.050	7.0	28.0	42.6	.....	.....	.....	.....
8	1.069	9.33	24.2	38.1	.....	.....	0.882	0.887
10	1.087	11.57	21.4	35.0	.....	.....	0.853	0.858
12	1.105	13.78	18.2	31.6	.....	.....	0.825	0.831
14	1.124	15.96	14.4	27.9	.....	.....	0.799	0.805
16	1.143	18.12	9.9	23.7	.....	0.768	0.775	0.781
18	1.162	20.24	4.7	19.4	.....	0.745	0.752	0.759
20	1.182	22.32	−1.0	15.0	.....	0.723	0.731	0.738
22	1.202	24.38	−7.3	10.7	0.695	0.704	0.711	0.718
24	1.223	26.41	−14.1	6.6	0.678	0.686	0.693	0.700
26	1.244	28.41	−22.0	2.6	0.663	0.670	0.677	0.683
28	1.265	30.39	−32.0	3.2†	0.649	0.656	0.662	0.669
30	1.287	32.34	−46.0	12.2†	0.638	0.643	0.648	0.655

* Source: "The Votator Book," 1949.

† Inches Hg below one atmosphere (29.92 in. Hg)

$\text{Baumé} = 145 - \dfrac{145}{\text{sp. gr.}}$ Salometer degrees = deg. Baum. l 4.0

Wt. of 1 gal = sp. gr. × 8.34

Wt. of 1 cu ft = sp. gr. × 62.4

Wt. NaCl or $CaCl_2$ in 1 gal = Wt. % × Wt. of 1 gal

Wt. NaCl or $CaCl_2$ in 1 cu ft = Wt. % × Wt. of 1 cu ft.

TABLE 23.2*. REFRIGERATION AVAILABLE PER POUND OF ICE AND SALT

Salt per 100 lb Water (lb)	Heat of Solution (Btu)	Total Heat of Resulting Solution (Btu)	Heat Required of Mixture per lb (Btu)
1	58.0	14,458	143.0
5	49.7	14,668	139.5
10	40.5	14,806	134.5
15	33.0	14,895	129.5
20	27.0	14,940	124.5
25	22.5	14,962	119.5
30	19.1	14,973	115.0
35	16.4	14,974	111.0

* Source: "Dairy Engineering," Farrall, John Wiley & Sons, 1942.

desired to obtain temperatures below 32°F when using ice; this is readily realized by mixing salt with the ice. Table 23.1 shows the temperatures obtained with various solutions of salt, using either sodium chloride ($NaCl$) or calcium chloride ($CaCl_2$), such temperatures corresponding to those listed in the "Freezing Point °F" column.

Table 23.2 shows the quantity of refrigeration available in Btu per pound of ice-and-salt mixture.

As ice-and-salt mixtures require constant care and attention and their bulk presents many practical problems, it is often found much more convenient to cool (or freeze) small quantities of food products with "Dry Ice" (solid carbon dioxide) which has found wide use in food industries because it refrigerates by *subliming* rather than by melting. Also, upon absorbing heat, it releases carbon dioxide gas which has some desirable preservative, or inhibitory, properties, in contrast to the corrosiveness and other saline effects of ice and salt mixtures. "Dry ice" is produced commercially as a by-product in various chemical production operations. The basic carbon dioxide gas is purified, compressed and liquefied, after which it is expanded rapidly to form a "snow," which in turn is pressed into blocks, forming the commercial product. It will produce a temperature of approximately −109°F in a CO_2 atmosphere and −123°F in a 50 per cent CO_2 atmosphere, has a density of 85 to 95 pounds per cubic foot and a refrigerating effect per pound (heat of sublimation from a solid at −109°F to a gas) of about 246 Btu. It is usually prepared and distributed in 50-pound cakes (about a 10-inch cube) and kept in well insulated cabinets. It is taken out and cut into slabs of appropriate size with a band saw as needed. It is so cold it has to be handled carefully with well insulated gloves, as it can freeze the tips of one's fingers very readily. In fact, it is usually separated from the product it is to refrigerate with insulating materials, such as corrugated paper board, as it will quickly freeze to a very low temperature any food with which it comes in contact.

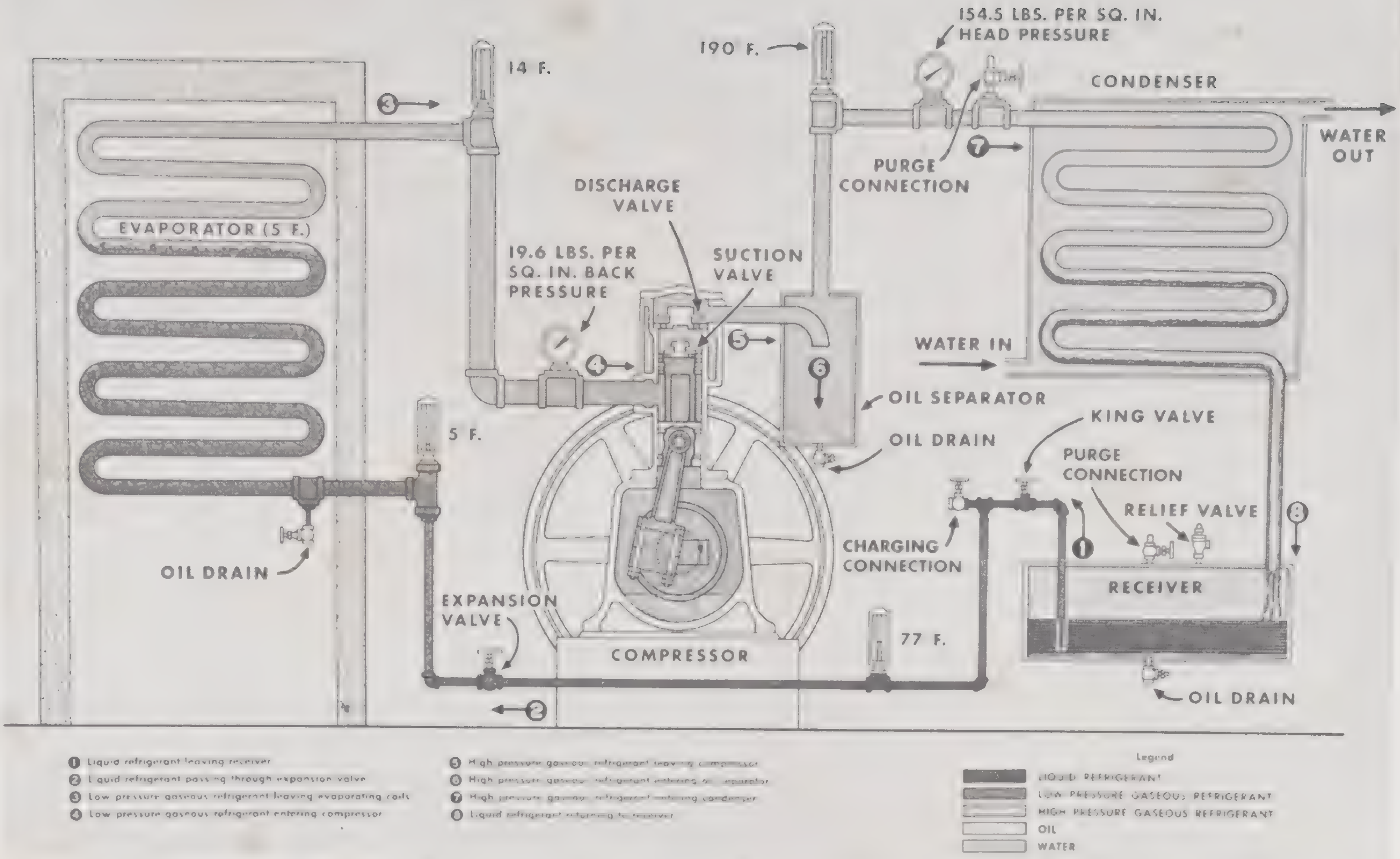
Artificial Refrigeration. This is accomplished by the mechanical compression system or the absorption system, both of which have a number of variations. The former is by far the most widely used commercially in food processing industries, largely because of its dependability, its ease of control and its relative simplicity. Its basic principles may be outlined as follows.

When a liquid evaporates, it absorbs heat and thereby cools its surroundings. Most commercial refrigeration operates on this basic principle which is applied in the so-called *mechanical compression system.* Thus, if liquefied ammonia is to be the refrigerating liquid, the fact that it boils at −28°F at atmospheric pressure is used to advantage.

Pure ammonia gas is mechanically compressed enough to liquefy it, and is then collected in pressure vessels, such as gas tanks or drums. In these containers, the ammonia is in a physical form such that, upon release of the pressure, it will boil and vaporize. If the outlet of the tank of liquefied ammonia is attached to a coil which passes through a brine tank, the ammonia introduced into the coil from the supply tank will begin to vaporize because of the reduced pressure and higher temperature conditions in the coil; in so doing it will absorb heat from the brine, thereby reducing its temperature. This cooling action will continue as long as any liquid ammonia is in the coils, until equilibrium has been established.

In actual practice, the refrigerating liquid is allowed to evaporate in coils or plates known as evaporators, and the gas formed is drawn off and compressed (see Fig. 23.1). Compression warms the gas, consequently it is passed through a condenser where it is cooled, either with running water or by circulating air with a fan. Cooling causes the compressed gas to reliquefy. The liquefied refrigerant is then collected in a pressure tank known as a receiver, from which it again passes through an expansion valve into the refrigerating coils or plates, thus completing the cycle. A relatively high pressure is maintained from the compressor to the condenser and in the receiver up to the expansion valve. Therefore, this side of the system is known as the high side, or high-pressure side.

Conversely, since the pressure from the expansion valve on through the refrigerator coils or plates (evaporators) up to the compressor is relatively low, this is known as the low side, or low-pressure side. Two methods are employed in supplying refrigerant to the evaporators: the conventional expansion valve arrangement, just discussed, and the flooded system. Expansion valves incidentally may be hand-controlled, pressure-actuated, or thermostatically controlled. In the flooded system, the refrigerant is usually fed to a surge drum or trap located above the evaporator; a definite level of liquid refrigerant is maintained in this surge drum by means of a float valve working on the ball-float principle. Liquid is fed by gravity from the drum to the refrigeration coils or plates, and the amount of refrigerant so fed is dependent upon its rate of evaporation.


154.5 LBS. PER SQ. IN.
HEAD PRESSURE
190 F.
14 F.
CONDENSER
WATER OUT
PURGE CONNECTION
DISCHARGE VALVE
SUCTION VALVE
EVAPORATOR (5 F.)
19.6 LBS. PER SQ. IN. BACK PRESSURE
WATER IN
OIL SEPARATOR
OIL DRAIN
KING VALVE
PURGE CONNECTION
RELIEF VALVE
5 F.
CHARGING CONNECTION
RECEIVER
OIL DRAIN
EXPANSION VALVE
COMPRESSOR
77 F.
OIL DRAIN
① ② ③ ④ ⑤ ⑥ ⑦ ⑧
① Liquid refrigerant leaving receiver
② Liquid refrigerant passing through expansion valve
③ Low pressure gaseous refrigerant leaving evaporating coils
④ Low pressure gaseous refrigerant entering compressor
⑤ High pressure gaseous refrigerant leaving compressor
⑥ High pressure gaseous refrigerant entering oil separator
⑦ High pressure gaseous refrigerant entering condenser
⑧ Liquid refrigerant returning to receiver
Legend
LIQUID REFRIGERANT
LOW PRESSURE GASEOUS REFRIGERANT
HIGH PRESSURE GASEOUS REFRIGERANT
OIL
WATER

Courtesy Creamery Package Mfg. Co.

FIG. 23.1. Flow diagram of compression refrigeration system.

In the *absorption system*, the increase in pressure is obtained by means of heat applied to aqua ammonia in a generator instead of by a compressor. The warm ammonia is cooled and liquefied in a condenser, as in the compression system. The liquid ammonia is fed through an expansion valve to the refrigerating coil or plate, where it vaporizes and absorbs heat, also as in the compression system. However, the gas returning from the expansion coils enters an absorber (corresponding to the suction end of the compressor) where it is absorbed in weak ammonia liquor cooled by cold water coils. From the absorber, the aqua ammonia is pumped to the generator. Here it is again heated, thus completing the cycle. After the aqua ammonia has given up most of its gas, it passes again to the absorber, where it is cooled and reabsorbs ammonia coming from the evaporator coils.

The capacity rating of refrigerating machines is based upon the rate at which they are capable of extracting heat under a given set of standard conditions. The ton, which is the common unit of capacity, is the equivalent of 288,000 Btu in 24 hours (200 Btu per minute or 12,000 Btu per hour) of continuous operation. This is also the amount of refrigeration accomplished by the melting of 1 ton of ice, as explained in the discussion of natural refrigeration. The standard ton, used in rating compressors, assumed that the heat is extracted from the evaporator at the above rate, the gas entering the compressor at 5°F and leaving it at a pressure corresponding in the refrigerant table to saturation at 86°F.

The *evaporator* or expansion coil—that part of the system in which the refrigerant boils and absorbs heat—is usually constructed of metal pipe or tubing. The materials depend upon the refrigerant used; steel pipe is the most practical for ammonia, while copper tubing is frequently used with "Freon" or carbon dioxide. Copper tubing is favored (whenever possible to use) because of its relative ease of handling and its favorable heat-transfer rate, although it cannot be used with ammonia because of the undesirable chemical action of ammonia on copper. Coils can be of the plain or finned type, the latter providing more efficient heat transfer, unless frosted over. The accumulation of oil and nonvolatile liquids inside coils will decrease their efficiency, regardless of the type used.

The *compressor* performs two functions: (1) it draws the cold vapor from the evaporator, while maintaining in it a low enough pressure to keep the boiling point of the refrigerant down to the point necessary to maintain the desired evaporator temperature; and (2) it pumps the vapor into the condenser, where it can be liquefied at ordinary temperatures by means of cooling water or air. Since the work done in a refrigeration system is dependent upon the pounds of refrigerant evaporated, and since a pound of refrigerant vapor occupies more space at a low pressure than at a higher one, it will be found that the capacity of the compressor varies as the suction pressure changes. In other words, as the suction pressure is lowered, more cubic feet of the vapor must be pumped per pound of refrigerant; consequently, the capacity of the compressor is reduced. Since any factor which causes the compressor to pump fewer pounds by weight of gas will decrease the capacity of the machine, capacity can be maintained by operating at a relatively high back pressure and by keeping the head pressure relatively low. It should always be kept in mind that the capacity of a compressor is also reduced when higher head pressures than necessary are used.

The function of the *condenser* is to remove sufficient heat from the vapors as they are discharged from the compressor so that they will be condensed back into the liquid, which can then be recirculated through the system. All the energy absorbed in the evaporator and in the compressor is taken out in the condenser, usually by water or air. The condenser operates at approximately the pressure equivalent to the liquefying temperature of the refrigerant under use. If ammonia is the refrigerant and the temperature of the cooling water is 70 F, the condensing pressure should not be higher than that equivalent to a temperature of 84 to 86 F for ammonia, or approximately 152 psi gage (see Table 23.3).

If the pressure, in the case of ammonia, exceeds 152 psi gage, several possible causes should be investigated. High head pressures cause reduced capacity and high power consumption. Usually excessive head pressures are due to air or other noncondensible gases in the system, or to the insulating effects of scale or dirt deposits on the cooling surface, provided of course that sufficient cooling water is passing through the condenser. Naturally, any appreciable increase in the temperature of the cooling water itself can also be a contributory factor. A commonly accepted value of 2 gallons per minute per ton refrigeration is the cooling-water requirement for refrigeration machines under average conditions.

The *direct expansion type of compression system* is very widely used today because it is more efficient and less expensive than the brine system. It does require, however, that the compressor be large enough to handle the maximum load at any one time. There are two types of direct-expansion coolers—the flooded and the expanding varieties. The flooded type (see Fig. 23.2) maintains at all times a fully loaded set of evaporating coils by means of a float valve with an accumulator to prevent liquid from being drawn back to the compressor. This easily regulated system is highly efficient and gives exceptionally high rates of heat transfer in heat exchangers, surface coolers, ice-cream freezers, and the like. One of its principal considerations is that all headers, pipes or tubes are large enough to carry the gas and liquid with the coils fully loaded. The plain expanding type is

TABLE 23.3*. PROPERTIES OF SATURATED AMMONIA VAPOR

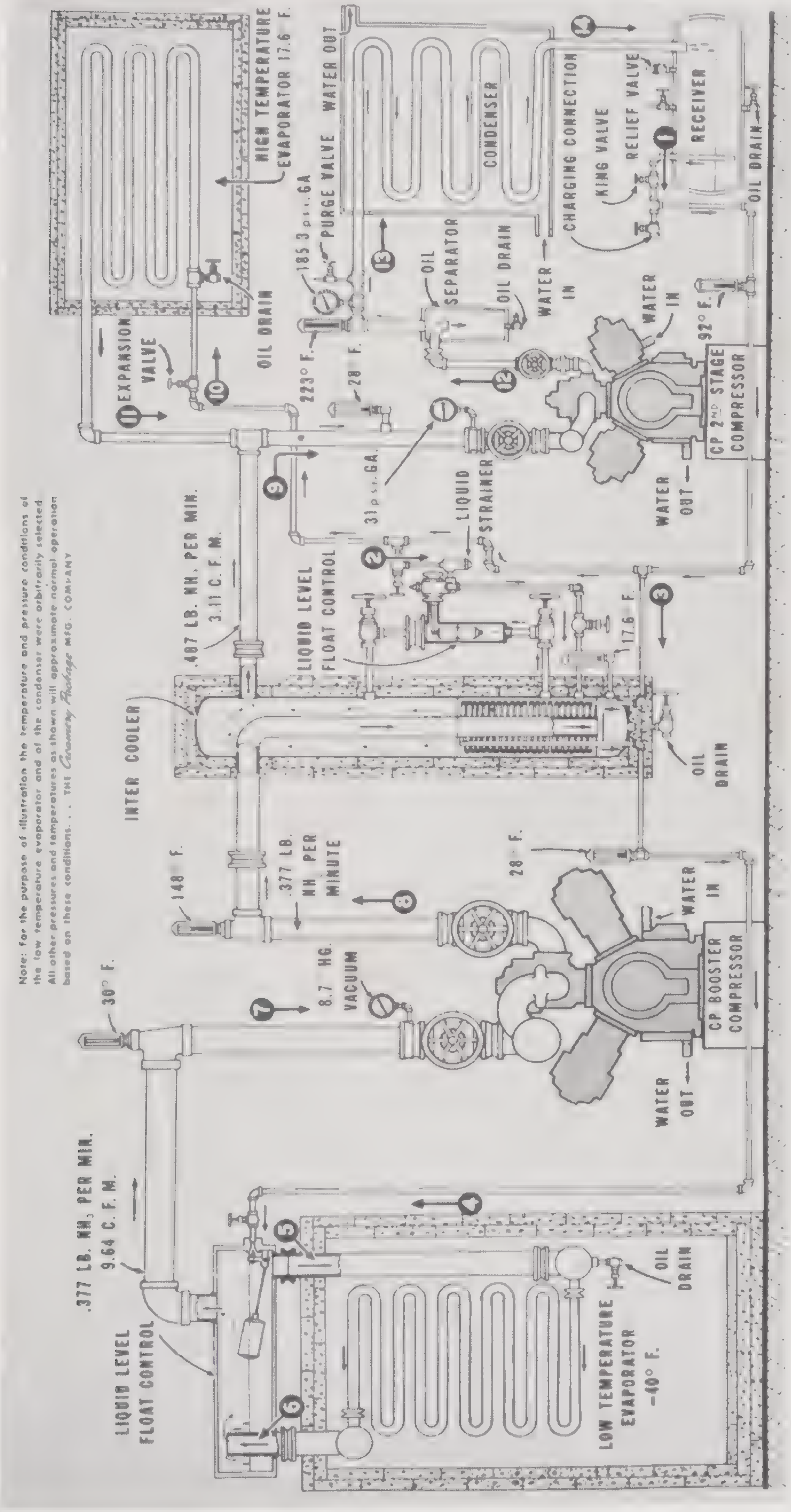
Temp (°F)	Pressure		Volume Vapor (cu ft per lb)	Weight Liquid (lb per cu ft)	Heat Content from −40°F (Btu per lb)		
	Absolute (psi)	Gage (psi)			Liquid	Latent (Evap)	Total Vapor
−50	7.67	14.3†	33.08	43.49	−10.6	604.3	593.7
−45	8.95	11.7†	28.62	43.28	−5.3	600.9	595.6
−40	10.41	8.7†	24.86	43.08	0.0	597.6	597.6
−35	12.05	5.4†	21.68	42.86	5.3	594.2	599.5
−30	13.90	1.6†	18.97	42.65	10.7	590.7	601.4
−25	15.98	1.3	16.66	42.44	16.0	587.2	603.2
−20	18.30	3.6	14.68	42.22	21.4	583.6	605.0
−15	20.88	6.2	12.97	42.00	26.7	580.0	606.7
−10	23.74	9.0	11.50	41.78	32.1	576.4	608.5
−5	26.92	12.2	10.23	41.56	37.5	572.6	610.1
0	30.42	15.7	9.116	41.34	42.9	568.9	611.8
5	34.27	19.6	8.150	41.11	48.3	565.0	613.3
10	38.51	23.8	7.304	40.89	53.8	561.1	614.9
15	43.14	28.4	6.562	40.66	59.2	557.1	616.3
20	48.21	33.5	5.910	40.43	64.7	553.1	617.8
25	53.73	39.0	5.334	40.20	70.2	548.9	619.1
30	59.74	45.0	4.825	39.96	75.7	544.8	620.5
35	66.26	51.6	4.373	39.72	81.2	540.5	621.7
40	73.32	58.6	3.971	39.49	86.8	536.2	623.0
45	80.96	66.3	3.614	39.24	92.3	531.8	624.1
50	89.19	74.5	3.294	39.00	97.9	527.3	625.2
55	98.06	83.4	3.008	38.75	103.5	522.8	626.3
60	107.6	92.9	2.751	38.50	109.2	518.1	627.3
65	117.8	103.1	2.520	38.25	114.8	513.4	628.2
70	128.8	114.1	2.312	38.00	120.5	508.6	629.1
75	140.5	125.8	2.125	37.74	126.2	503.7	629.9
80	153.0	138.3	1.955	37.48	132.0	498.7	630.7
85	166.4	151.7	1.801	37.21	137.8	493.6	631.4
90	180.6	165.9	1.661	36.95	143.5	488.5	632.0
95	195.8	181.1	1.534	36.67	149.4	483.2	632.6
100	211.9	197.2	1.419	36.40	155.2	477.8	633.0
105	228.9	214.2	1.313	36.12	161.1	472.3	633.4
110	247.0	232.3	1.217	35.84	167.0	466.7	633.7
115	266.2	251.5	1.128	35.55	173.0	460.9	633.9
120	286.4	271.7	1.047	35.26	179.0	455.0	634.0
125	307.8	293.1	0.973	34.96	185.1	448.9	634.0

* Source: "The Votator Book," 1949. (*From Bureau of Standards Circular No. 142*).

† Inches Hg below one atmosphere (29.92 in. Hg).

often used when a simple system is required and when rapid fluctuations in demands do not normally occur—usually in those cases where manual regulation is sufficiently accurate.

Among refrigerants, ammonia is commonly used, particularly in large cold storage warehouse and freezer installations. Fluorinated hydrocarbons, such as dichlorodifluoromethane, commonly known as "Freon-12" (see



Note: For the purpose of illustration the temperature and pressure conditions of the low temperature evaporator and of the condenser were arbitrarily selected. All other pressures and temperatures as shown will approximate normal operation based on these conditions. . . THE *Creamery Package* MFG. COMPANY

FIG. 23.2. Flow diagram of a CP Booster compression refrigeration system.

Courtesy Creamery Package Mfg. Co.

TABLE 23.4*. PROPERTIES OF SATURATED "FREON-12" (CCl_2F_2) VAPOR

Temp (°F)	Pressure		Volume Vapor (cu ft per lb)	Weight Liquid (lb per cu ft)	Heat Content from −40°F (Btu per lb)		
	Absolute (psi)	Gage (psi)			Liquid	Latent (Evap)	Total Vapor
−40	9.32	10.9†	3.91	94.6	0.	73.50	73.50
−35	10.60	8.3†	3.47	94.1	1.01	73.09	74.10
−30	12.02	5.4†	3.09	93.6	2.03	72.67	74.70
−26	13.26	2.9†	2.82	93.2	2.85	72.33	75.18
−24	13.90	1.6†	2.70	93.0	3.25	72.16	75.41
−20	15.28	0.6	2.47	92.6	4.07	71.80	75.87
−16	16.77	2.1	2.27	92.2	4.89	71.45	76.34
−14	17.55	2.8	2.18	92.0	5.30	71.27	76.57
−10	19.20	4.5	2.00	91.6	6.14	70.91	77.05
−6	20.98	6.3	1.84	91.1	6.99	70.53	77.52
−4	21.91	7.2	1.77	90.9	7.41	70.34	77.75
0	23.87	9.2	1.64	90.5	8.25	69.96	78.21
5	26.51	11.8	1.48	90.0	9.32	69.47	78.79
10	29.35	14.6	1.35	89.4	10.39	68.97	79.36
14	31.80	17.1	1.25	89.0	11.26	68.56	79.82
16	33.08	18.4	1.21	88.8	11.70	68.35	80.05
20	35.75	21.0	1.12	88.4	12.55	67.94	80.49
24	38.58	23.9	1.04	87.9	13.44	67.51	80.95
26	40.07	25.4	1.01	87.7	13.88	67.29	81.17
30	43.16	28.5	0.94	87.2	14.76	66.85	81.61
34	46.42	31.7	0.88	86.8	15.65	66.40	82.05
36	48.13	33.4	0.85	86.5	16.10	66.17	82.27
40	51.68	37.0	0.79	86.1	17.00	65.71	82.71
50	61.39	46.7	0.67	84.9	19.27	64.51	83.78
60	72.41	57.7	0.57	83.8	21.57	63.25	84.82
70	84.82	70.1	0.49	82.6	23.90	61.92	85.82
80	98.76	84.1	0.42	81.4	26.28	60.52	86.80
90	114.3	99.6	0.37	80.1	28.70	59.04	87.74
100	131.6	116.9	0.32	78.8	31.16	57.46	88.62
110	150.7	136.0	0.28	77.5	33.65	55.78	89.43
120	171.8	157.1	0.24	76.0	36.16	53.99	90.15

* Source: "The Votator Book," 1949. (*From tables by Kinetic Chemicals, Inc.*).
† Inches Hg below one atmosphere (29.92 in. Hg).

Table 23.4) and similar compounds, are being used in many of the smaller commercial installations such as household refrigerators, ice-cream cabinets, and home freezers. Methyl chloride, methylene chloride and ethyl chloride are employed in some small commercial units and a few makes of household refrigerators. Carbon dioxide is sometimes used on shipboard and where unusually low temperatures are required. Brines are not used nearly as much as formerly, although they are still employed in the so-called "brine cooling" of many existing cold storage areas.

Refrigerants are often transported in pipe coils mounted on walls and ceilings around which air circulates and loses heat. Instead of pipes, the refrigerating gas or liquid may flow between two metal surfaces called *plate coolers*. As the air of a room comes in contact with the cold pipes, it becomes heavier and tends to settle to the bottom of the room, thus forcing warmer air to rise. This starts a natural circulation known as *gravity coil circulation*. In some cases, coils are grouped and mounted within a cabinet having suitable openings, with fans so arranged as to force air through or over the coils into the space to be cooled by what is known as *forced air cooling*. These various methods of producing low temperatures are utilized in a variety of ways; for example, intense cold for a short period is usually produced by an air blast over direct-expansion coils and directed into a restricted area, such as a tunnel. On the other hand, a freezer that may be used for long holding periods with a minimum of possible dehydrating effects would generally require a gravity coil circulation system. These demands of the types and degrees of refrigeration vary in accordance with the commodities and processes to which they are applied.

The Cold Storage of Foods

Spoilage of fresh food is usually the result of decay caused by biological agents such as bacteria or fungi, changes in composition brought about by respiration and enzymic action, and the development or absorption of undesirable odors. All food is contaminated to some extent with bacteria and fungi that are likely to cause rapid decay if the food is kept at normal room temperature or higher. The activity of the decay organisms is retarded by lower temperatures, although some of them will continue to develop slowly, even at freezing temperatures.

Enzymes cause desirable changes, such as ripening, but when such changes continue too long, over-ripeness and undesirable breakdown occur. Enzymic activity is reduced about half for every 20° F decrease in temperature, and only below 0° F is it kept at a minimum. Fresh fruits and vegetables are still alive after harvesting and continue to respire in storage. During the respiration process, atmospheric oxygen combines with the carbon of the plant tissues, which occurs chiefly in the form of sugars and starches, to form various decomposition products, and finally carbon dioxide and water. The respiration rate of fruits and vegetables may be reduced by lowering the temperature, reducing the amount of oxygen, increasing the concentration of carbon dioxide, and removing the gases that stimulate respiration. Stored foods may absorb undesirable odors from other foods, decaying foods or even environmental odors, such as those contributed by building materials, etc.

The cold storage requirements of most of the important perishable foods have been carefully evaluated, studied and recommended by authoritative investigators; they are compiled in considerable detail in the Refrigeration

Data Book published by the American Society of Refrigerating Engineers, the most recent edition of which was published in 1952. Most of the data given are based on the storage of commodities shortly after harvesting. When products have been transported considerable distances, or have been permitted to stand at ordinary air temperatures for any appreciable length of time, appropriate allowances must be made. The temperatures recommended are usually those considered to be optimum for long storage, and refer to actual commodity temperatures rather than air temperatures. The reader is advised to consult this and other reliable sources for specific details concerning individual commodities, as it is not possible to state any over-all optimum storage conditions.

The optimum storage temperature for many foods has been found to be just above their freezing points. Knowledge concerning these freezing points has therefore been useful to the cold storage industry in determining how the various commodities should be handled in storage. Accordingly, knowledge of the moisture content of foods is useful to the food engineer as a basis for calculating specific heats and the latent heat of freezing. The specific heat of foods is ordinarily calculated by Siebel's formula

$$S = 0.008a + 0.20$$

where S represents the specific heat of the substance containing a per cent of water; 0.20 is the value representing the specific heat of the solid constituents of the substance.

The composition of foods varies with numerous factors. For this reason, variations in data compiled from different sources are to be expected and should be no cause for alarm. It must also be kept in mind that in tables of the specific heats of various foods compiled by different authors, slightly different formulas in making calculations are often used. In cases of doubt, it probably will be wise to use the higher values. However, the specific heat and other values should be determined for the sample in question, if the work justifies close tolerances.

It is important to remember that fresh fruits and vegetables in cold storage are alive, and carrying on within themselves processes characteristic of living things. In particular, the heat of respiration must always be considered a part of the refrigeration load in handling fruits and vegetables. The approximate rate of evolution of heat by various commodities is given in Table 23.5.

Although refrigeration is usually the most effective method for retarding spoilage of fresh food, supplemental treatments are beneficial in some cases, and are especially valuable where only moderately low temperatures are used during a part or all of the storage period. Among the supplemental treatments are controlled atmospheres, air purification, ozone, sterilizing lamps, fumigants, antiseptic washes, and treated fruit wrappers. Obviously, TABLE 23.5*. APPROXIMATE RATE OF EVOLUTION OF HEAT (BTU PER TON PER 24 HR) BY CERTAIN FRESH FRUITS AND VEGETABLES WHEN STORED AT THE TEMPERATURES INDICATED

Commodity	32°F	40°F	60°F
Apples	300–600	590–820	2,270–3,470
Bananas†	–	–	–
Beans			
Green or snap	5,000–6,610	9,160–11,390	32,090–44,130
Lima	2,330–3,000	4,300–6,100	21,990–27,410
Beets, topped	2,650	4,060	7,240
Broccoli, sprouting	7,450	11,630	33,870
Cabbage	1,200	1,670	4,080
Carrots, topped	2,130	3,470	8,080
Celery	1,620	2,420	8,220
Cherries	1,320–1,760	—	11,000–13,200
Corn, sweet	6,560	9,390	38,410
Cranberries	600–720	870–970	1,650–1,800
Cucumbers	1,690	2,550	10,460
Grapefruit	460	1,070	2,770
Grapes			
American type	600	1,170	3,490
European type	300–430	—	—
Lemons	580	810	2,970
Lettuce	11,320	15,990	45,980
Melons, cantaloupes	1,320	1,960	8,500
Mushrooms	6,160	22,000	58,000
Onions and Onion Sets	660–1,100	1,760–1,980	—
Oranges	690–900	1,400	5,000
Peaches	850–1,370	1,440–2,030	7,260–93,010
Pears	660–800	—	8,800–13,200
Peas, green	8,160	13,220	39,250
Peppers, sweet	2,720	4,700	8,470
Potatoes	440–880	1,000–1,760	2,200–3,550
Raspberries, red‡	—	—	15,400–17,600
Spinach	4,240–4,860	7,850–11,210	36,920–38,000
Strawberries	2,730–3,800	5,130–6,600	15,640–19,140
Sweet Potatoes	1,190–2,440	1,710–3,350	42,800–38,400
Tomatoes			
Mature green	580	1,070	6,230
Ripe	1,020	1,260	5,640
Turnips	1,940	2,150	5,280

* Source: "ASRE Refrigerating Data Book," 1952.

† Turning ripe at 68°F, 8360. ‡ At 36°F, 4,400–6,600.

maintenance of the proper storage temperature and the optimum condition of relative humidity is essential to correct storage conditions. The relative humidity of the air in the storage warehouse or room is a factor of significant economic value, as at refrigeration temperatures, foods lose moisture due to evaporation unless this is checked by the proper humidity control.

Loss of moisture causes not only loss of weight in the stored commodities but also wilting of vegetables and shrinking and drying of fruits. The humidity requirement for different foods varies, but in general the foods with the higher moisture contents require the higher relative humidities for optimum storage conditions. For such reasons, the humidity requirements are always stated as are the temperature requirements in commercial food storage specifications.

The Freezing Preservation of Foods

Perishable foods are usually stored at temperatures above freezing for relatively short periods—a week or two in the case of some fish, up to six weeks for meat, and for a maximum period of one year in the case of gas-stored apples. On the other hand, most frozen foods keep satisfactorily at 0°F for at least a year if previously frozen to −10 or −15°F. It should be borne in mind, however, that the freezing operation is only one of a number of steps, each of which is important in preparing frozen foods of high quality. As previously emphasized, each unit operation in processing commercial foods contributes its increment in retaining the maximum qualities of the original fresh food in its processed end-product. *Good quality cannot be engineered into foods, but retention of good quality can be achieved by engineering techniques.*

The freezing preservation of foods probably dates back into antiquity, at least in cold climates. However, most of the present practices of freezing foods are of fairly recent origin. The artificial freezing of fish and poultry came into use on a commercial scale about 1865, when sharp freezing was employed. The freezing preservation of meat began about 1880. The cold-packing industry began about 1905 with freezing of small fruits for use in jams, jellies, pies and ice cream. Commercial quick-freezing of vegetables and fruits started about 1929, as did the freezing of consumer-size packaged fish, meat and poultry. Some precooked foods appeared in the early 30's, and the first volume packs of precooked frozen foods about 1942.

It was not until the economic importance of frozen foods began to be recognized, and equipment was available for its distribution, that any appreciable scientific study was devoted to the essential details of its proper preparation and holding. Previously, little or no attention had been given proper selection, hence many products were frozen for which there was no market. Their slow sales rate contributed to their further deterioration, with the result that most products compared very poorly with fresh or canned foods. In addition, most products had been frozen in bulk, usually in sharp freezers.

A large proportion of the commercial production of frozen foods is still performed in sharp freezers. A *sharp freezer* is merely a room which can be maintained at a low temperature, usually −10°F or lower, throughout the freezing operation. It may adjoin other cold rooms utilized for storage purposes. In some sharp freezers, the pipes or coils carrying the refrigerating medium are arranged as shelves on which are placed the products to be frozen; in others, freezing is accelerated by forced-air circulation, using fans and diffusers. It usually requires several hours for the food products subjected to such methods to solidify. Since it takes from 3 to 72 hours, depending upon the bulk of the product and the methods and facilities utilized, the term "slow freezing" has come to be applied to sharp freezer practice, in contrast with modern methods of "quick freezing."

Quick Freezing. The quick freezing process is applied to carefully selected food products usually in unit package form (or such other form as would expedite its freezing). Realizing that air is a relatively poor conductor of heat, the food engineer recognizes its limitations (as well as its possibilities) in attaining rapid heat extraction. Upon investigating, he finds that quick freezing can be accomplished in three ways, namely: (1) *direct immersion* of the food in the refrigerating medium itself (obviously, the most efficient means from an engineering point of view); (2) *indirect contact* with the refrigerant, as by conduction through metal plates; and (3) *forced convection* of refrigerated air directed at heat-transfer surfaces.

A quick-frozen food is readily distinguishable by these general characteristics:

(1) its contained ice crystals are so small that they cause minimum damage to its cellular structure;
(2) its diffusion of indigenous salts and its separation of water in the form of ice is at a minimum;
(3) its biological activity (decomposition) is arrested and restrained by the rapidity of the extraction of heat from its mass.

As might be expected, heat loss (extraction) rates vary with the nature of the product, but the differences are much less than those observed in heat penetration. It is true that the temperature differential between the product and the surrounding atmosphere governs the rate of heat loss, but the differential is usually much less in freezing than in heating operations. The cooling of products in small containers is five times as fast in "Dry Ice" at −110°F as in air at −2°F; consequently, the freezing period (the period of constant temperature during and after ice formation) is very much shorter in "Dry Ice" than in air.

Ice formation first occurs at the heat-extracting surface, and subsequent ice formation proceeds in the direction of the warmer mass while conducting heat from the warmer area to the refrigerating medium. We find this interesting fact confirmed in ice manufacture. In metal cans containing water that are immersed in a cold brine bath, the ice first forms on the inner sides of the can. With a 14°F brine, ice first appears when the water in the center of the can reaches 40°F, while with an 18°F brine, ice first appears when the water reaches 38°F. Furthermore, in a 14°F brine bath, water in cans will drop from 70 to 40°F in approximately 15 minutes, but the chilling thereafter down to 32°F requires an additional 40 to 50 minutes. Furthermore, the extent of both brine and water turbulence influences the cooling rates to a marked degree. From these observations, it appears that the extraction of heat from water in the early stages of its cooling may be due to convection currents within the water mass, but that after ice is formed in the areas of greatest temperature differential, the ice starts to remove heat from the water by conduction.

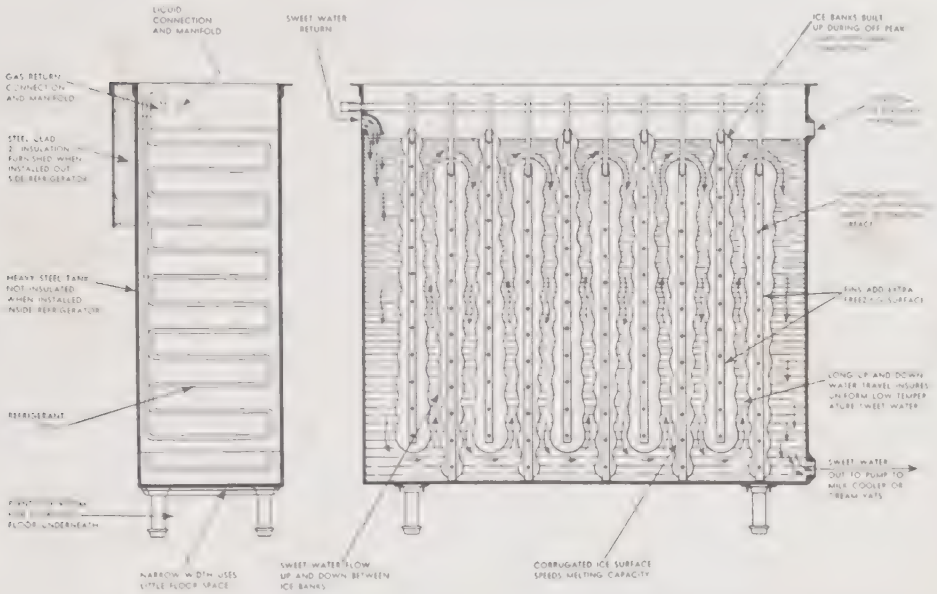
From the foregoing discussion of the principles of refrigeration and of the cold storage conservation of foods, we have gained an insight into the complexities of extracting heat from a food mass. Such incidental processing as was involved was largely of an environmental character, in the sense that it prepared food (and truly gigantic quantities at that) for a temporary retardation of biological activities which would otherwise hasten its decomposition. To actively process food so as to leave unimpaired its original characteristics of freshness and general wholesomeness for long periods, there is no question that freezing it in proper form is the correct method. Actually, freezing preservation involves only two states of matter: liquid and solid. However, gases are involved to the degree that they are often incorporated in foods to improve their palatability—a factor of considerable significance, as has been previously emphasized.

THE FREEZING OF LIQUID FOODS

Iced "Sweet" Water

Food-processing plants occasionally need ice water (34°F) for washing and/or tempering purposes in connection with certain food products as well as for cooling purposes. In the final cooling of milk, cream and other dairy products, a supply of ice-cold water with a uniform temperature of 34°F in a so-called "sweet" water combined cooling and storage tank is often helpful. The basic ideas involved in such an automatic system of sweet water cooling are: (1) to utilize the fact that as ice melts it absorbs 144 Btu of heat per pound of ice melted; and (2) to generate a reserve supply of ice, thus insuring an iced-water cooling capacity within a minimum of space. The melting point of ice being uniformly at 32°F, the temperature of the ice water will not vary appreciably from 34°F as long as an adequate supply of ice is available.

For such purposes, a small compact rectangular steel tank may be fitted with vertical fin type coils, creating a large amount of refrigerating surface (see Fig. 23.3). These coils are connected to a relatively small direct-expan-


LIQUID CONNECTION AND MANIFOLD
SWEET WATER RETURN
ICE BANKS BUILT UP DURING OFF PEAK
GAS RETURN CONNECTION AND MANIFOLD
STEEL CLAD 2" INSULATION FURNISHED WHEN INSTALLED OUTSIDE REFRIGERATOR
HEAVY STEEL TANK NOT INSULATED WHEN INSTALLED INSIDE REFRIGERATOR
REFRIGERANT
FLOOR UNDERNEATH
NARROW WIDTH USES LITTLE FLOOR SPACE
SWEET WATER FLOW UP AND DOWN BETWEEN ICE BANKS
CORRUGATED ICE SURFACE SPEEDS MELTING CAPACITY
FINS ADD EXTRA FREEZING SURFACE
LONG UP AND DOWN WATER TRAVEL INSURES UNIFORM LOW TEMPERATURE SWEET WATER
SWEET WATER OUT TO PUMP TO MILK COOLER OR CREAM VATS

Courtesy Cherry Burrell Co.

FIG. 23.3. Iced "sweet" water generator and storage tank.

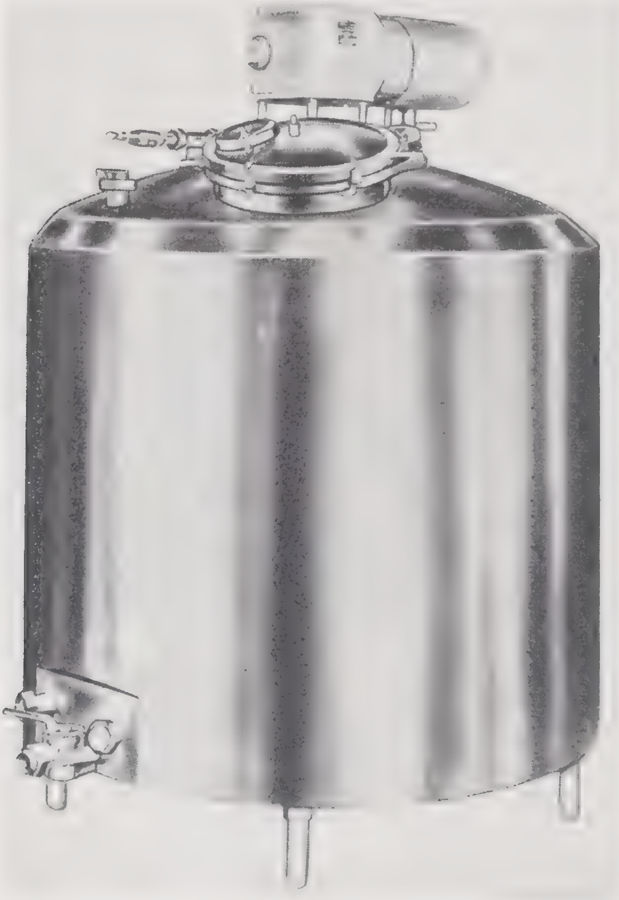
sion compression refrigerating system. When no cooling is taking place, the coil will be freezing the water in its immediate area and simultaneously building up a bank of ice frozen onto the fin coils. This operation will continue until a sufficient bank of ice has thus been generated to establish a 34°F temperature in the remaining water in the tank, when a thermostatically operated control will shut off the ice machine compressor.

When the ice water supply is used for cooling purposes, it soon absorbs enough heat to start melting the ice bank. (Due to the latent heat of fusion of ice, 144 Btu will be required to melt each pound of ice to form one pound of water.) When the temperature of the water supply tends to exceed 34°F as a result of the absorbed heat, the thermostatic control starts the compression system again for the generation of more ice. Incidentally, when the temperature of the water supply tends to drop below 34°F, the ice machine is again shut off to prevent complete freezing of the ice-water supply.

Fruit Juices and Concentrates

Fruit juices not intended for immediate consumption must be subjected to some preservation process to prevent spoilage. The most satisfactory method of preserving the fresh fruit flavor of many juices fruit is by freezing. In this case they may not need preliminary heat treatment, although for satisfactory results they should be adequately prechilled before packaging for freezing. Orange, pineapple and tomato juices should be completely deaerated before freezing, and it has been found that flash-heating to 190°F after deaeration is advantageous, though not essential. Apple, cherry, raspberry and loganberry juices can be frozen satisfactorily in large containers providing the juice has been chilled before being placed in the containers in which it is to be frozen. The packing of fresh fruit preserved by freezing is limited by the expense and problems related to distribution and use. The juice must be held at 0 to 15°F until thawed for use, as not all microorganisms are destroyed by freezing. Frozen concentrated citrus and grape juices, especially those concentrated in vacuum at temperatures low enough not to affect their delicate flavors, have proved highly successful.

The usual method of freezing these concentrated fruit juices after adjusting their composition to the proper Brix degree, is to pass them through heat exchangers, such as a Votator or slushing tanks (see Fig. 23.4), in which their temperature is rapidly reduced to 15 to 18°F. After this they are immediately canned, sealed, cartoned and placed in storage at −10°F. To re-



Courtesy Mojonnier Bros. Co

FIG. 23.4. Slush freezing and blending tank.

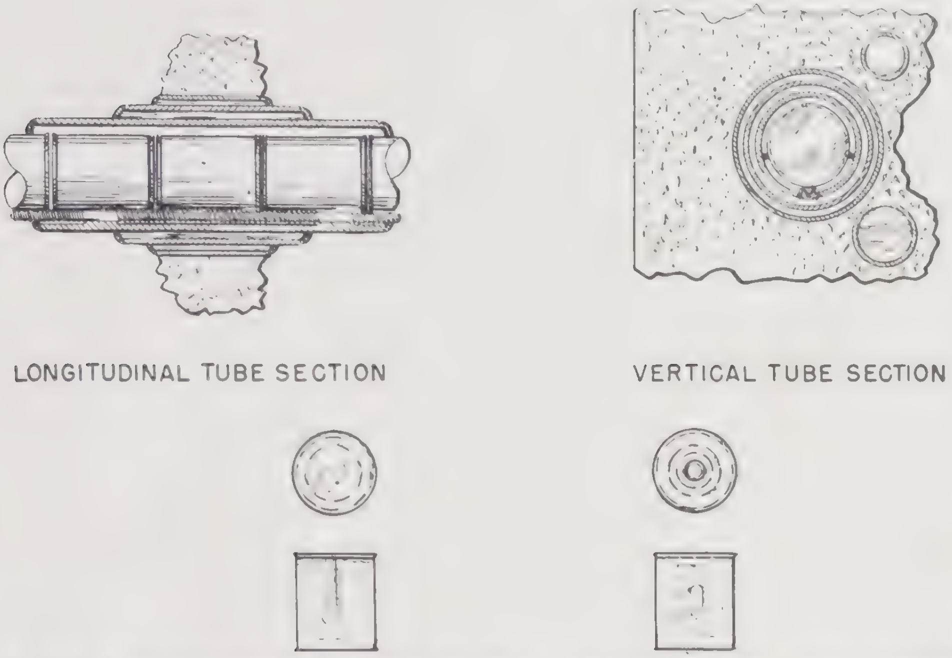


FIG. 23.5. Longitudinal and vertical sections of a typical tubular freezer showing freezing formation ordinarily developed.

tain their fresh flavors, all fruit juices and concentrates must be frozen as soon as possible after preparation. Chilled juices or concentrates packed in cans and then frozen in the containers give satisfactory results when frozen rapidly. Considerable quantities of orange juice have been frozen in cans with excellent results, using Finnegan tubular freezers in which sealed cans of juice are passed through tubes filled with rapidly flowing refrigerated alcohol (see Fig. 23.5). Containers should not be filled to more than nine-tenths of their capacity with unfrozen juice, to allow for expansion during freezing. Appropriate allowances should also be made for concentrates, depending upon the freezing characteristics of the concentrations in which they are frozen. It is now generally conceded that the nature of citrus juices makes imperative the use of hermetically sealed containers; in conjunction with vacuum sealing and the proper enamel lining these have been found essential in preserving citrus juices by quick freezing and by subsequent freezer storage.

Much discussion and speculation still persists as to what constitutes the optimum rate of freezing for various foods. Because of the almost endless variation of types, varieties, maturities and similar factors of quality determination, it is probable that this uncertainty will continue. However, when an optimum rate has been established, it is important that it be closely related to the temperature of the heat-transfer medium and to the design of the heat exchanger used, since it is known that sub-zero temperatures are uneconomical to maintain and cause injury to some foods.

Quick freezing does not necessarily require use of extremely low temperatures. We have already seen (Chapter 21) how proper agitation of the head space can enhance the mixing of the contents of a can so that processing time can be reduced to less than one-fifth the conventional period. Similarly, it seems reasonable that freezing processes might be hastened considerably by proper agitation during withdrawal of heat from a liquid food, as will be illustrated presently.

To the food engineer, "quick freezing" means the expedited rate of heat flow relative to a given temperature; he is more concerned with ways of speeding up the heat flow by reducing the resistance offered to heat exchange (as well as other factors tending to retard heat flow), than with using extremely low temperatures to accomplish their requirements. It is necessary, therefore, to know what factors affect heat transmission in each case before resistance can be predicted or before an effective and economical means of expediting heat exchange can be devised. It is equally important to apply any acceleration of heat transfer throughout the refrigerating system to a final evaporating temperature since it is the over-all heat-transfer coefficient that gives a reliable measure of the efficiency of a freezing system as of any other heat-exchanging system.

According to formula (5) of Chapter 22 (page 246) involving the turbulent flow of water inside smooth pipes, the heat flow from water to pipe or pipe to water depends on film conductance. While this formula indicates the importance of film resistance to heat flow, it does not contain a correction factor for v, or mean velocity, in cases where the cross-sectional area of the pipe is restricted. This, of course, increases the value of h considerably, since the heat-transfer coefficient varies inversely with the 0.8 power of mean velocity. When engineers calculate fluid velocities through pipes or tubes, they usually consider only the mean velocity, which is equal to the discharge divided by the area of the cross section of the pipe. In other words, $Q = av$, where Q is the quantity discharged in cu ft/sec., a is the area in sq ft, and v is the mean velocity in ft/sec. However, the actual velocities in the cross section are considerably greater than the mean velocity near the center, and very much less near the interior surfaces of the tube or pipe. A restriction in the cross section of a tube formed so as to allow only a narrow flow near the interior surfaces materially increases the heat transfer from or to the surfaces being contacted with a heat-transfer medium, as we have demonstrated in drum-type heat exchangers equipped with internal rotors to keep the thickness of flow to a minimum

Ice Cream

In freezing an ice-cream mix, we are confronted with several unusual circumstances, all of which must be taken into account from an engineering point of view. First, the ice-cream freezer has two functions to perform: (1) freezing the mix to the desired consistency, and (2) whipping in the desired amount of air in a finely divided condition. The usual aim is to conduct the freezing and subsequent hardening so as to obtain the smoothest possible texture.

Secondly, in making ice cream, we are freezing a mixed solution. The solutes which determine its freezing point are the lactose and the soluble salts contained in the serum solids, and the sugars added as sweetening agents. The other ingredients of the mix affect the freezing points only indirectly, by displacing water and affecting the in-water concentration of the solutes mentioned.

Leighton[1] has developed a reliable method for computing the freezing points of ice-cream mixes from their known composition. He totals the lactose and sucrose contents of the mix, expressing their concentration in terms of parts of sugar per 100 parts of water, and determines the freezing-point depression due to the sugars by reference to published data for sucrose. This is justified, since lactose and sucrose[2] have the same molecular weight.

$$\%\ \text{lactose in mix} = \%\ \text{serum solids} \times 0.545$$

$$\frac{(\%\ \text{lactose} + \%\ \text{sucrose}) \times 100}{\%\ \text{water in mix}} = \text{parts lactose} + \text{sucrose per 100 parts water}$$

To the freezing-point depression caused by these sugars he adds the depression which will be caused by the soluble milk salts. The depression caused by the salts is computed as follows:

$$\text{Freezing-point depression (°C) caused by serum solids} = \frac{\%\ \text{serum solids} \times 2.37}{\%\ \text{water in the mix}}$$

Table 23.6 gives the freezing points of various ice creams and a typical sherbet and an ice, as computed by Leighton's method, according to Sommer[3].

The freezing point, of course, merely represents the temperature at which freezing commences. As with all solutions, the unfrozen portion becomes more concentrated as freezing progresses, and its freezing temperature therefore decreases. In a simple solution, containing only one solute, this

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[1] Leighton, *J. Dairy Sci.*, **10**: 300 (1927).

[2] Dextrose or glucose (corn sugar) depresses the freezing point 1.9 times as much as sucrose.

[3] Sommer, H. H., "ASRE Refrigeration Data Book," Applications Volume, 4th ed., 1952.

TABLE 23.6. FREEZING POINTS OF TYPICAL ICE CREAMS, SHERBET, AND ICE

Composition of the mix (%)					
Fat	Serum Solids	Sugar	Stabilizer	Water	Freezing Point (°F)
8.5	11.5	15	0.4	64.6	27.59
10.5	11.0	15	0.35	63.15	27.57
12.5	10.5	15	0.30	61.7	27.55
14.0	9.5	15	0.28	61.22	27.68
16.0	8.5	15	0.25	60.25	27.79
10.5	8.4	Sucrose 12 Dextrose 4	0.40	64.7	27.39
Sherbet					
1.2	1.0	Sucrose 22 Dextrose 8	0.50	67.3	25.97
Ice					
0	0	Sucrose 23 Dextrose 9	0.50	67.5	25.68

* Source: Sommer, H. H., "ASRE Refrigeration Data Book," 1952

trend continues until the unfrozen portion represents a saturated solution of the solute, and thereafter the temperature remains constant until freezing is completed. This temperature is known as the *cryohydric point* of the solute.

In an ice-cream mix, with its several sugars and various salts, no such point can be recognized. On the contrary, the indications are quite definite that the sugars remain in solution in a supersaturated state in the unfrozen portion of the product. This is apparently because, by the time the saturation point has been reached, the temperature is so low and the viscosity so high as to produce essentially a "glass state." It is interesting to note, however, that in a mixed solution the temperature required for complete freezing must be somewhat below the cryohydric point of that solute which has the lowest cryohydric point. In the case of ice cream, that solute is calcium chloride, contained as a natural component of serum solids. The cryohydric point of calcium chloride is −67°F. Accordingly, we may say that the ice cream varies from 0 per cent frozen to 100 per cent frozen between the approximate temperatures of 27.5 to −67°F.

Consequently, the temperature to which ice cream has been chilled becomes a measure of the degree to which it has been frozen. This is illustrated by Table 23.7, in which the freezing points of the unfrozen portions have been computed when from 0 to 90 per cent of the original water has been frozen out as ice. For this purpose the third ice cream of Table 23.7 has been selected as being most typical of normal operations.

Exact calculations of refrigeration requirements in the freezing of ice cream is complicated by the number of factors involved. The specific heat of the mix varies with its composition. While a number of detailed calculations can be performed in any consideration of its various components, it is

TABLE 23.7*. FREEZING BEHAVIOR OF A TYPICAL ICE CREAM†

Water Frozen to Ice (%)	Freezing Point of Unfrozen Portion (°F)	Water Frozen to Ice (%)	Freezing Point of Unfrozen Portion (°F)
0	27.55	40	24.40
5	27.35	45	23.63
10	27.05	50	22.62
15	26.78	55	21.42
20	26.40	60	19.79
25	26.04	70	14.99
30	25.70	80	5.14
35	25.03	90	−22.29

* Source: Sommer, H. H., "ASRE Refrigeration Data Book," 1952.

† Composition: fat, 12.5%; serum solids, 10.5%; sugar, 15%; stabilizer, 0.30%; water, 61.7%.

common practice to assume a specific heat value of 0.80 for ice-cream mix; this figure is generous for mixes ranging from 36 to 40 per cent total solids. In calculating the refrigeration required in freezing and hardening, one is scarcely justified in speaking of a specific heat for frozen ice cream. As has been shown in Table 23.7, any change in temperature in freezing and hardening involves some latent heat of the water, as well as the sensible heat of the unfrozen mix and the ice. The heat units that become involved as latent heat of fusion (or to be more precise, of solidification) per degree temperature change differ according to whether the temperature change is near the initial freezing point or farther along in the freezing process. In the former case, much more latent heat is involved per degree temperature change than is true in well-hardened ice cream, e.g., at −10 to −11°F. For this reason it is preferable, instead of using an over-all figure in terms of specific heat, to compute as follows:

(1) Having in mind the temperature to which the freezing is to be carried, determine by calculations such as those employed in connection with Table 23.7, how much water will be converted to ice. Then the pounds of water frozen × 144 will give the Btu to be removed.

(2) To compute the sensible heat that must be removed in the desired temperature change, treat the problem as though the product were mix, i.e., use the specific heat value for ice-cream mix. Then °F temperature change × lb of product × 0.80 will give the Btu to be removed as sensible heat.

In such a calculation the water present is treated as though it all remains liquid until the desired temperature is reached, when as a matter of fact ice forms progressively. Since ice has a specific heat of 0.492 instead of 1.0 as for water, this calculation will err in the direction of generous refrigeration. Offsetting this is the fact that in the freezer there is vigorous agitation, which develops heat of friction, or mechanical heat. It has been estimated that approximately 80 per cent of the energy input in the motor of the freezer is converted to heat in the product. When it is frozen to a stiff consistency and power requirements are thus increased, additional allowance should be made for this factor, even though the discrepancy of the above calculation is involved.

Since capacities are ordinarily figured in terms of gallons of ice cream, it becomes necessary to convert gallons to pounds of product. The weight of a gallon of ice-cream mix varies from 9.0 pounds for mixes with high fat to 9.25 pounds for mixes with low fat, high serum solids and high sugar contents. The weight of a gallon of ice cream varies with the mix weight and the percentage of overrun. The relationship between weights and overrun is as follows:

$$\% \text{ overrun} = 100 \times \frac{\text{Wt per gal mix} - \text{Wt per gal of ice cream}}{\text{Wt per gallon of ice cream}}$$

To obtain ice cream of smooth texture, the ice crystals and air cells must be small. To some extent these two phases are interdependent. Crystallization should take place rapidly to yield small crystals, preferably with agitation and with liberal "seeding." All three of these requirements are met in the ice cream freezer: (1) the *rate of crystallization* is much more rapid than later in the hardening process; (2) the freezer provides agitation, whereas hardening does not; (3) "seeding" is produced in the freezer by the process of freezing the film of mix adjacent to the wall and scraping it off with the blades. (Seeding may be by numerous fine ice particles or fewer coarse particles, according to the efficiency of the scraping process, which in turn is influenced by the sharpness of the blades, their angle of contact, and their actual contact with the entire freezing area.) As a result of these nearly ideal conditions, the aim should be to accomplish as much of the operation as possible in the freezer itself. There will then be correspondingly less water to be frozen in the hardening process, and more ice crystals onto which the additional ice can build. While conditions are less ideal in the hardening than in the freezing operation, the rate of crystallization is still of decided importance. In slow hardening, the tendency is to deposit the ice onto crystals already in existence, while in rapid hardening new crystals will form, with a resulting smoother texture.

In the actual freezing of ice cream, either batch or continuous operations may be employed. In batch freezers, usually of about 40- to 100-quart capacity, enough mix and flavoring material are placed in the freezer to fill it to slightly less than half of its actual capacity, thus allowing room for whipping in air. With the scraper and dasher mechanism in motion, refrigeration is applied by circulating brine through the jacket of the freezer, or by opening the suction valve in flooded-system, direct-expansion freezers. In either case, the refrigerant temperature is adjusted to about −10 to

−15°F. Freezing is allowed to continue until the desired consistency has been acquired and the refrigeration is then turned off. This point may be anticipated in cases where the additional refrigeration, trapped in the freezer, is too great.

Whipping is continued until the desired overrun has been obtained, as can readily be determined with a tared, metered cup. During this operation, the temperature will tend to rise slightly because of mechanical heat and imperfect insulation. If the mix is too slow in whipping, the temperature rise will ultimately make successful control of the overrun impossible. In addition to temperature rise, churning, which inevitably occurs to some extent, is detrimental to whipping quality.

When the desired overrun has been reached, the freezer must be emptied with reasonable speed. This naturally limits the consistency to which ice cream may be frozen, as will also the optimum consistency for whipping, lest it be passed and thus make it impossible to attain the desired overrun. For this reason, the whipping properties of mixes to be frozen in batch operations are important, for if the whipping ability is high, it will be possible to freeze to the maximum stiffness without sacrificing overrun. A drawing temperature of 24°F is usually about as low as can be successfully achieved with batch freezers.

From the foregoing discussion, it is apparent that careful overrun control is essential to a satisfactory product. Since overrun relates to the percentage increase in volume of the ice cream as compared with that of its basic mix, it is evident that this is a very important factor in palatability. The usual ice-cream mix without the incorporated air is likely to prove insipid to most people, primarily as a result of its high sugar and milk solids contents, normally about 15 per cent and 10 per cent, respectively. When the proper amount of air is incorporated, the insipid mix becomes highly palatable. Yet if an excessive amount of overrun is permitted its flavor characteristics begin to diminish, and the consumer gets the impression of tasting a light-bodied whipped cream. To regulate overrun, standards such as 1.6 lbs. of total food solids per gallon of ice cream, or a weight of 4.5 lbs. per gallon of ice cream, are set by some states. In addition, most states require 10 per cent fat for vanilla ice cream, with 18 per cent total milk solids and 30 to 33 per cent total solids, whereas other states require a 12 per cent fat standard, and a few specify 14 per cent. Other flavored ice creams have varying requirements.

In the operation of continuous freezers, the control of the mix and air in specified proportions are metered by pumping through the freezing chamber under positive pressure. The limitation of consistency to which ice cream may be frozen does not apply, as in the case of batch freezing, as both the continuous stream and the positive pressure propel the stiffer ice cream through the apparatus. Since the whipping proceeds under pressure, the stiffness or consistency does not have the limitation of optimum conditions for air incorporation. The air is in a compressed state, and in the freezing chamber where the agitation is vigorous the mix is not required to take a high overrun; under the comparatively gentle agitation incident to the discharge flow and expansion to atmospheric pressure, the air remains incorporated.

According to the design and operational characteristics of the freezer, the pressure under which the freezing and whipping occur ranges from 30 to 100 psi. Under these conditions it is possible to freeze the ice cream to a stiff consistency, so that it holds its shape with little tendency to flow. The usual drawing temperature is 21°F, and in some instances a little lower. From Table 23.7 it is evident that continuous operation converts appreciably more of the water into ice than do batch freezers; in addition, the texture of the finished product is definitely smoother.

Upon delivery from either batch or continuous operation, ice cream should be placed in the hardening room as promptly as possible. Any partial melting is detrimental to texture, as the resulting water will form large ice crystals on refreezing. The hardening is accomplished by placing the filled containers of ice cream in a refrigerated room where the temperature is below 0°F, preferably at −10 to −15°F. Hardening rooms refrigerated by natural convection are now rarely used, but have been largely superseded by the still-air type, wherein most of the expansion coils serve as shelving. In recent years, the trend has been toward the forced convection type of hardening room, and the advent of the continuous freezer has hastened this trend. Movement of air in the hardening room accelerates hardening of ice cream, and with positive circulation of the frigid air, it is possible to reduce the hardening time to about one-half its normal rate.

Eggs

In the foregoing pages, we have considered among the liquid foods those of low viscosity (fruit juices) and medium viscosity liquids (ice cream), with the added problems of freezing when air is incorporated. The freezing of eggs has also been selected as an example of frozen food production for two reasons: (1) because present practice still employs the older form of sharp freezing in most instances, and this has wide application among other liquid foods; (2) because the frozen egg industry has grown to enormous proportions and the demand for high-grade frozen egg products has been steadily increasing. Using information from various sources, it has been estimated that in 1951 approximately 88.5 per cent of the eggs produced in this country were used as shell eggs, 6 per cent frozen and as liquid eggs, and 1 per cent dried. This means that about 333 million pounds of eggs were frozen.

Practices vary greatly as to the specific types of eggs used in frozen products. It almost goes without saying that in the case of frozen products, only good raw material will result in good food when thawed. Obviously inedible eggs cannot be used. Eggs should be handled properly before they are used for breaking purposes. In general, adequate refrigeration will effectively prevent deterioration brought about by physical and chemical influences and microbiological growth. High temperatures should be avoided if quality is to be maintained, as such conditions permit liquefaction of the egg contents, with weakening and spreading of the yolk. Accompanying these changes is a transfer of water from the white to the yolk. Eggs of watery whites and weak yolks are difficult to handle in the breaking room when separating whites from yolks.

Egg-breaking plants are best located in areas producing good eggs in plentiful quantities. Great emphasis must be placed upon sanitation in the breaking rooms with respect to surroundings, utensils and equipment. The eggs generally are broken one at a time and placed in a cup holding two to four eggs. These eggs, if satisfactory in appearance and odor, are emptied into a larger container, and are eventually placed in a mixer (generally called a "churn") and agitated until the mixture becomes homogeneous. Pasteurization of liquid eggs has been studied intensively during recent years, with some definite trends toward the utilization of plate heat exchangers. Effective pasteurization conditions appear to be provided in the application of 142°F for 3 minutes for liquid whole egg, 142°F for 2 minutes for liquid yolk, and 134°F for liquid white; this treatment results in a 99 per cent reduction of bacterial counts.

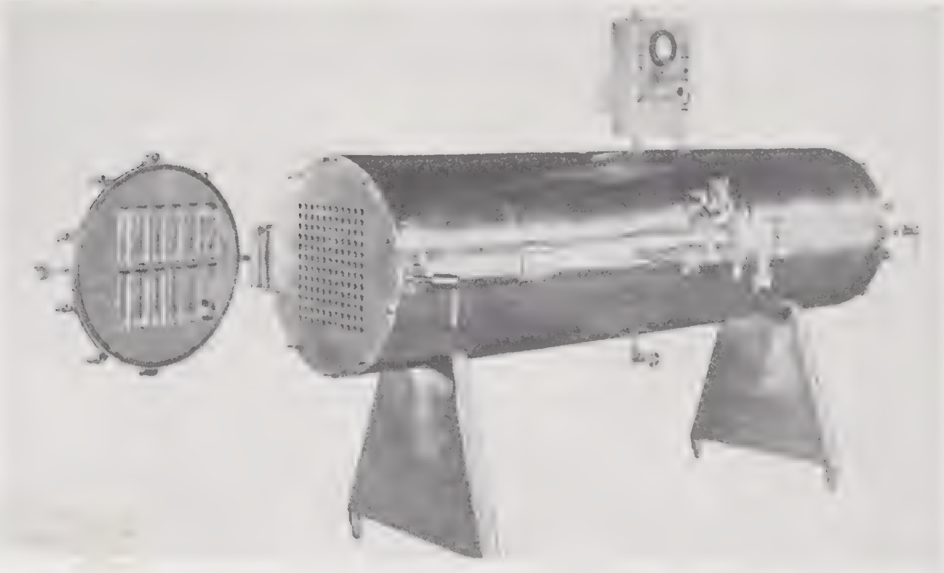
Frozen eggs may consist of a mixture of whites and yolks in natural proportions, or the whites and yolks may be frozen separately. After mixing, the egg liquids are passed through a fine wire screen to remove the strings of chalazae and fragments of shell. From the churn, the products are either pasteurized and cooled or are delivered directly into containers, usually 30-lb. tin cans, and transferred at once to sharp freezers. Liquid eggs are usually frozen to, and held at, 0°F in order to maintain quality. A 30-pound container of whole eggs will freeze to 0°F in still air in 28 hours at −24°F, in 32 hours at −15°F, and in over 44 hours at 0°F. Air-blast freezing and specially designed quick-freezing units may be used to secure a much more rapid freeze. The frozen product may be tempered or partially defrosted by holding up to 48 hours at 40°F, or up to 24 hours at 60°F. Defrosting the container and its contents in cold running water is the ideal method where the proper equipment is available.

Types of Heat Exchangers

In the generation and storage of iced water supplies, the sweet water is recirculated by appropriate pumping means and by proper placement of the freezing coils. As illustrated in Fig. 23.3, adequate circulation of the stored water is provided by natural convection currents stimulated by the staggered placement of the coils. Obviously, insulation of the combined ice-generating and iced water storage tank prevents too rapid heat absorption from the surrounding atmosphere, unless the tank is installed in a refrigerated room, the temperature of which is maintained at approximately 34°F. In the plate-pasteurizing systems, a 34°F water supply for cooling milk or cream not only insures proper cooling but prevents freezing of milk onto the plates, which may occur with a direct-expansion cooling system. For this reason, most plate-pasteurizing systems now utilize such iced water cooling supplies as the refrigerant for their final cooling operation. The operation of the freezing coils is thermostatically controlled to avoid complete freeze-up of the iced water supply.

In the freezing of citrus concentrates, we referred to the use of the Votator heat exchanger for rapidly reducing temperatures to 15-18°F before filling the cans for subsequent storage in a sharp freezer. Since this type of heat exchanger was thoroughly discussed in Chapter 22, no further comment is necessary on its application in the quick-freezing operation. However, in Fig. 23.4 is shown a slushing tank which performs a similar function. Shell and tube heat exchangers are also used for cooling liquid and semiliquid food products, some of the more modern units using ammonia or "Freon" operating on the full-flooded principle (see Fig. 23.6).

The modern batch ice-cream freezer consists of a refrigerator drum or

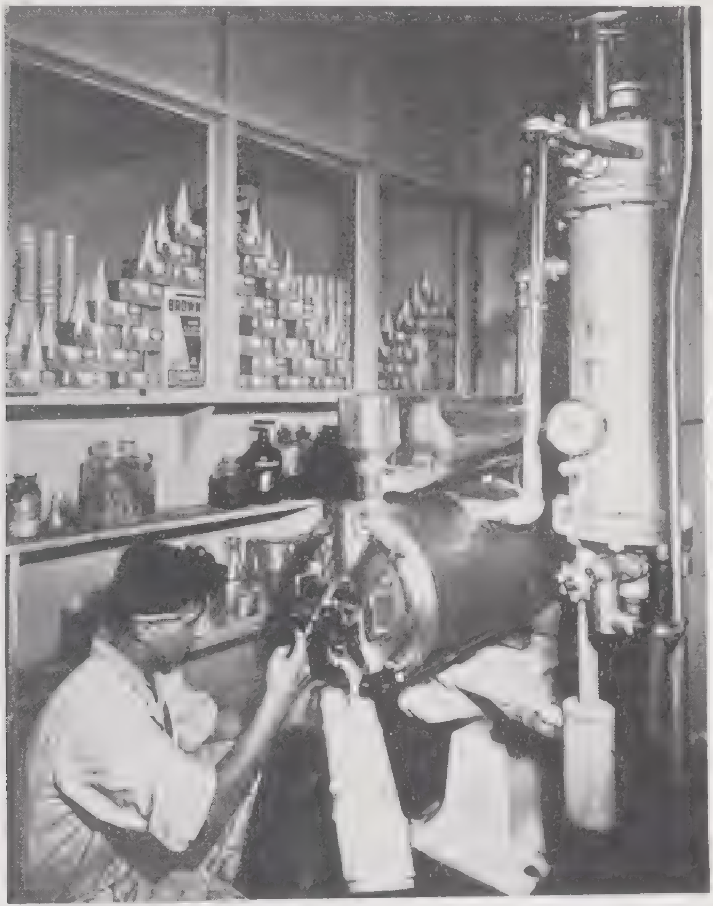


Courtesy Mojonnier Bros. Co.

FIG. 23.6. Shell and tube heat exchanger. This heat exchanger is used for cooling liquid and semiliquid food products with ammonia or "Freon" which operates on full-flooded principle.

cylinder, usually of 40- to 100-quart capacity, mounted on a base with direct motor drive, which rotates a dasher having scrapers for removing the frozen mix from the refrigerated surface and a beater for whipping in air. There is also a mix tank above the freezing cylinder and a hopper at the top front end of the cylinder for adding fruits and flavor. At the lower front end of the cylinder is a sliding valve for withdrawing the frozen ice cream (see Fig. 23.7).

The modern continuous freezer employs the same fundamental principles of operation as the batch freezer, in that the product is cooled to a plastic state and mixed with a given percentage of air. The major difference is that continuous machines freeze the ice cream under pressure. This has the advantage of improving the heat transfer and permits incorporation of air even when freezing at the lower temperatures of 21 to 22°F; a resulting stiffer product with overruns of 100 per cent and more is thus obtained.



Courtesy Creamery Package Mfg. Co.

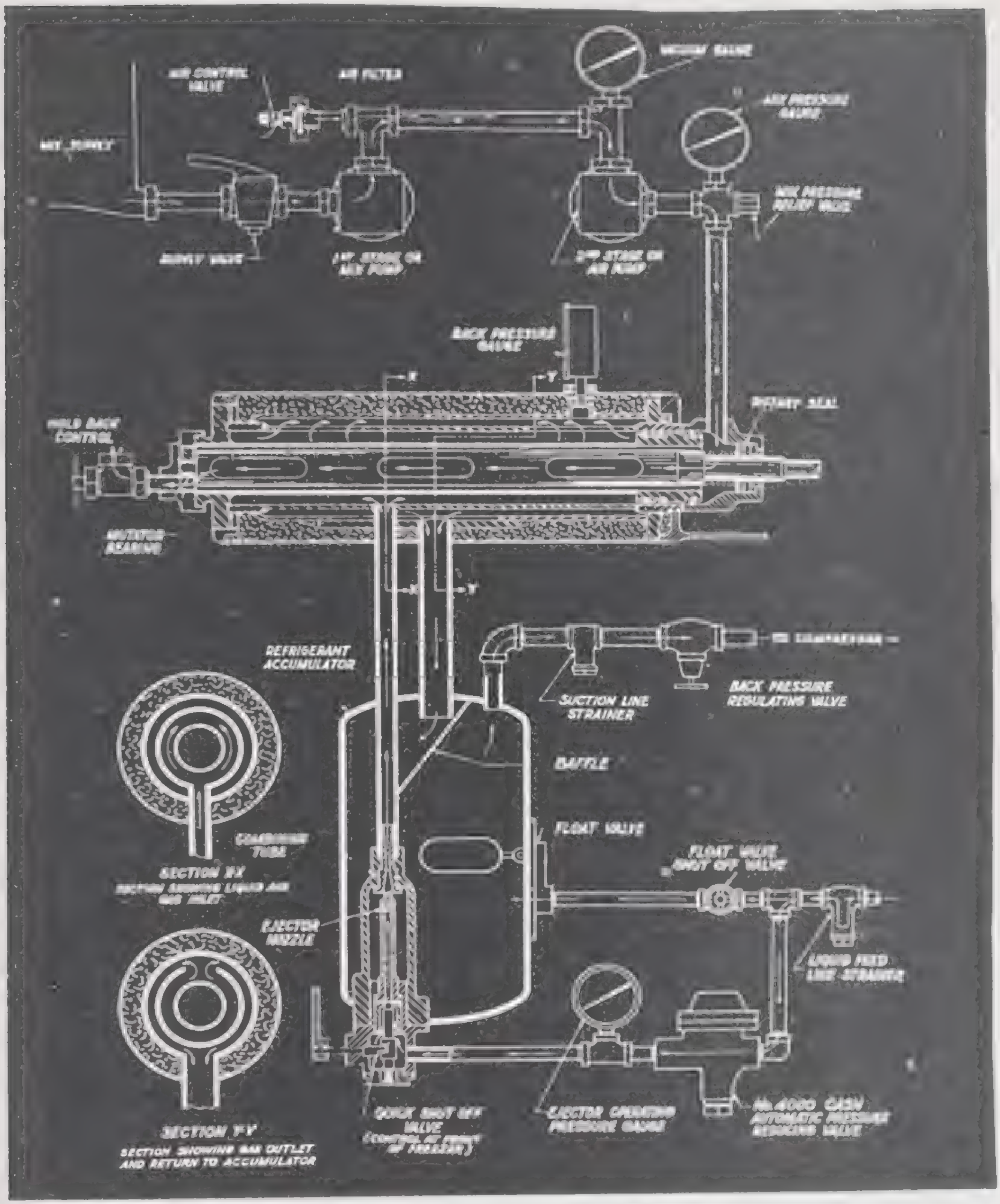
FIG. 23.7. Withdrawing ice cream from batch freezer, 40 quarts being frozen in 6 minutes.

Continuous freezers are also equipped with pumps which control the percentage of mix and air as well as supply the pressure necessary to force the stiff ice cream through the machines and into containers.

As early as 1908, a Mr. Meisenhelter of York, Pennsylvania, developed an ice cream freezer which incorporated such features as metering of the air and mix and freezing under pressure. In 1926, a Mr. Vogt applied for a patent on an improved continuous freezer embodying several interesting principles. He followed the basic idea of the Meisenhelter freezer, but added a direct-expansion cooling system and a tube-shaped freezing cylinder which caused extremely fast freezing and provided the heat-exchanging principles now employed in the Votator heat exchanger. The principle of the Vogt freezer is illustrated in Fig. 23.8. Observe that metered amounts of mix and air are forced into the freezing tube by the mix and air pumps, the frozen mixture being forced out the other end of the tube by pressure of the second pump, assisted by the hold back control at the discharge end of the freezing tube. The principal advantages of this freezer are its ability to produce an extremely smooth ice cream at low temperature and to discharge it into cartons or other containers. The temperature of the product is controlled by the ammonia temperature or by the rate of flow of the ice-cream mix. The overrun is controlled by the amount of air pumped into the freezer with the mix.

The second pump has a capacity several times that of the first, and therefore draws a vacuum in the header where a small adjustable orifice with the proper control valve allows air to be drawn in. This air, together with the mix from the first pump, is then forced into the freezing tube by the second pump. By allowing more or less air to enter the manifold, the percentage of overrun is increased or decreased. The dasher, or mutator shaft, of the Vogt freezer leaves only a small annular space between its displacement surfaces and the freezing tube wall for the ice cream to pass (see Fig. 23.9). It is equipped with three blades, which give more frequent scraping of the film from the cylinder wall at lower mutator speed than the two-blade solid mutator shaft used in the Votator heat exchanger, for example. The large eccentric displacement member which operates within the tubular shaft of the mutator serves the purpose of a beater and gives greater displacement of the mix in the freezing cylinder, resulting in faster response to overrun changes. This has eliminated the need of inner beaters and has also resulted in a simpler hollow mutator shaft which is easier to clean and to assemble.

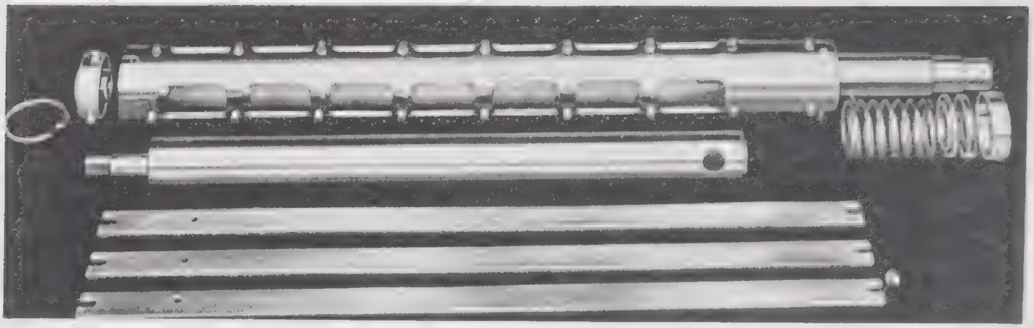
The Creamery Package continuous freezer (see Fig. 23.10) has a freezing cylinder of larger diameter than the Vogt machine, and resembles that of the conventional batch-type freezer. The ammonia system is of the full flooded gravity-feed type, with a float control to maintain a predeter


AIR CONTROL VALVE
AIR FILTER
MIX SUPPLY
AIR PRESSURE GAUGE
MIX PRESSURE RELIEF VALVE
SUPPLY VALVE
1ST STAGE OF MIX PUMP
2ND STAGE OF AIR PUMP
BACK PRESSURE GAUGE
ROTARY SEAL
HOLD BACK CONTROL
TO COMPRESSOR
REFRIGERANT ACCUMULATOR
SUCTION LINE STRAINER
BACK PRESSURE REGULATING VALVE
BAFFLE
FLOAT VALVE
COMBINING TUBE
SECTION X-X
SECTION SHOWING LIQUID AND GAS INLET
FLOAT VALVE SHUT OFF VALVE
EJECTOR NOZZLE
LIQUID FEED LINE STRAINER
SECTION Y-Y
SECTION SHOWING GAS OUTLET AND RETURN TO ACCUMULATOR
QUICK SHUT OFF VALVE (CONTROL AT FRONT OF FREEZER)
EJECTOR OPERATING PRESSURE GAUGE
No. 4000 CASH AUTOMATIC PRESSURE REDUCING VALVE

Courtesy Cherry Burrell Corp.

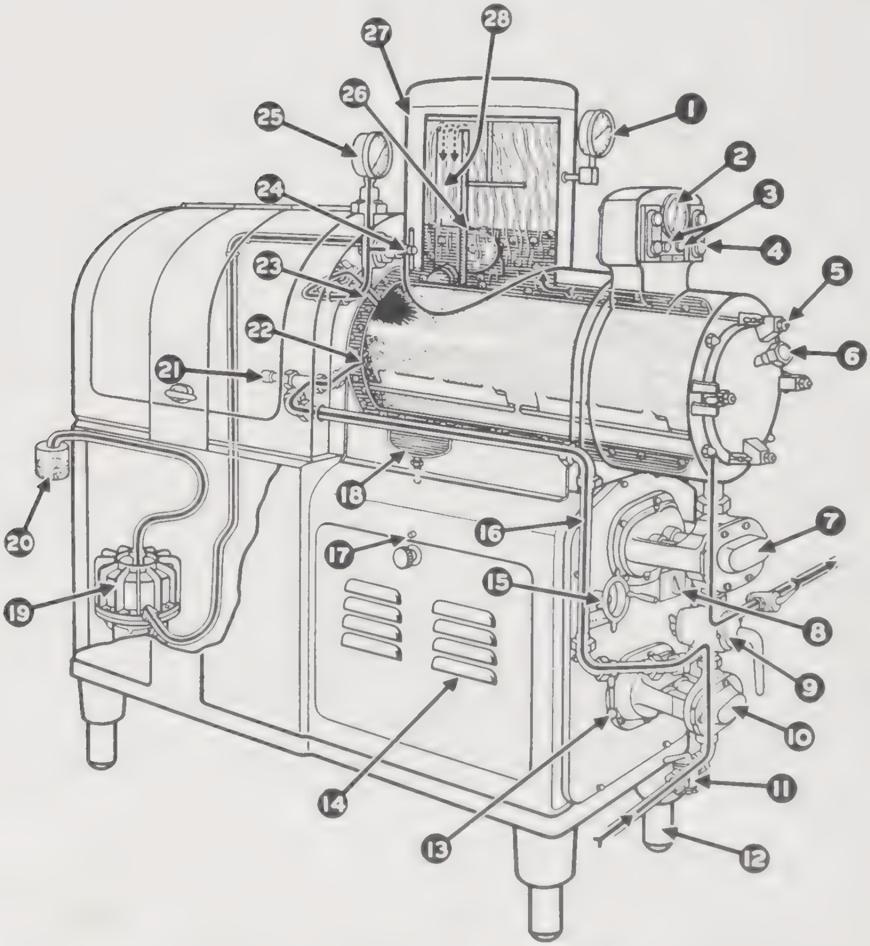
FIG. 23.8. Diagram of the Vogt continuous ice-cream freezer.

mined level of liquid ammonia in the accumulator, which is integral with the freezing cylinder. This level is approximately one foot above that of the freezing cylinder to provide sufficient gravity head for the circulation of the ammonia. The ammonia temperature is regulated by means of an



Courtesy Cherry Burrell Co.

FIG. 23.9. Disassembled hollow mutator shaft with blades, eccentric displacement member and rotary seal parts are shown separately.



Courtesy Creamery Package Mfg. Co.

FIG. 23.10. Diagrammatic view of the creamery package continuous ice-cream freezer

adjustable back pressure-regulating valve. An oil trap is located at the bottom of the ammonia chamber which surrounds the freezing chamber. The system is similar to that used in batch machines of the flooded ammonia direct-expansion type of refrigeration. The overrun control on this machine is unique in that it employs a metering-type pump for controlling the flow of mix into the freezing cylinder, another metering pump for controlling the flow of ice cream from the cylinder, and an air pump which supplies an excess of air at all times. The freezing is done under pressure, determined by the setting of an air-pressure regulator, which in turn controls the overrun. The mix pump and the ice-cream pump are driven from a common source and at a predetermined capacity ratio so that, no matter what the speed of the mix pump, the ice-cream pump will always pump a certain fixed percentage of increased volume. By this arrangement, the ratio of ice cream output to mix input is theoretically kept constant regardless of capacity changes, and therefore the capacity may be changed without upsetting the overrun. The added volume of ice cream over that of the mix consists of air absorbed by the ice cream as it passed through the freezer. As air is supplied in excess quantity, the ice cream is free to absorb neither more nor less than the difference in the output of the ice cream pump as compared to the input of the mix pump. As long as the relative speeds of the two pumps are kept constant, the overrun will be constant. To vary the overrun it is merely necessary to change the output of the ice cream pump while keeping the input of the mix pump constant.

Calculation of Refrigeration Load in a Freezer

A study of the heat balance and thermal relations of any freezer involves not only the product to be frozen and the freezing system, but also the power consumption. It is true of any freezer that the amount of refrigeration which must be extracted is made up of heat exchanges from three sources, namely: (1) cooling of the product, (2) radiation losses, and (3) heat equivalent of energy expended in agitating the product while it is being frozen. A typical problem in the freezing of ice cream will illustrate the points mentioned above:

Problem: Find the refrigeration in Btu necessary to freeze 150 gallons of ice cream delivered at 21°F, per hr from a 40°F mix of the composition 12.5% fat, 10.5% serum solids, 15% sugar, 0.30% stabilizer in a freezer requiring a $7\frac{1}{2}$ hp motor to drive the dasher. Assume that 85% of the heat equivalent of work done by the motor appears as heat in the ice cream. Consider the radiation loss as 3%; overrun as 100%. (It is assumed that the specific heat of semifrozen ice cream is 0.65).

Solution: Total Refrigeration (Btu) = Heat absorbed from mix + Heat of friction + Radiation loss.

Heat absorbed from mix:
Sensible heat = $(40 - 27.55) \times 0.8$ = 9.96 Btu
Latent heat = $(.54 \times .617) \times 144$ = 48.08 Btu
Sensible heat of slush = $(27.55 - 21) \times 0.65$ = 4.26 Btu

Total heat extracted from mix = 62.30 Btu
1 gallon of mix weighs 9.10 lb
Total Btu per hr from mix = $150 \times 4.55 \times 62.3$ = 42,520 Btu
Heat absorbed from friction:
7.5 hp $\times$ 2.545 $\times$ 0.85 = 16,224 Btu
Total refrigeration required, excluding radiation = 58,744 Btu
Radiation losses: = 1,762 Btu

Total Refrigeration required: = 60,506 Btu
= 5.04 tons

THE FREEZING OF SOLID FOODS

Freezing of Fruits and Vegetables

Although we have discussed some of the distinguishing characteristics of quick-frozen foods, the term"quick freezing" is largely relative. Indeed, there may be far greater advantage in quick-freezing flesh foods of animal or fish origin than fruits and vegetables, since the structure of the latter is made up of inelastic, cellulosic tissues, which often split during the expansion that takes place in freezing, either slow or quick. The form of starchy products like peas is partially supported by the mass of starch granules retained in a semi-pervious skin. Asparagus is supported by bundles of woody fibers which increase in toughness with maturity; yet it becomes very flabby after defrosting, although leakage is somewhat greater in slow- than in quick-frozen asparagus. In strawberries, the breakdown is so severe that even the fastest possible rate of freezing is of little help.

Nevertheless, the rate of freezing is of great importance in minimizing quality losses due to bacterial and enzymatic activities. Once bacterial action starts, slow convection freezing in a cold room or in an overcrowded blast freezer will remove heat so slowly that biological activity can continue to generate heat for several hours right in the freezer. For this reason, a freezing operation cannot overcome the deficiencies of other operations, unless the capacity of the freezer is adequate to freeze the product in minutes rather than in hours.

In spite of the great damage which may occur to the texture of some fruits, such as the strawberry, freezing is by far the best known method of preserving flavor and color. Large quantities of fruits are frozen annually in the United States; strawberries, cherries, raspberries and other small berries, peaches and apples make up the bulk of the pack.

Much fruit is slow or sharp frozen in large containers for the use of jam.

jelly and preserve makers, bakers, ice cream makers, and other large institutional users. This type of product is generally known as "cold pack" or "frozen pack." A smaller quantity of fruit, consisting mainly of strawberries, raspberries and peaches, is quick-frozen in small containers for use by consumers in making desserts. As freezing, storing and thawing fruits cause undesirable changes in texture as well as in color and flavor, fruits are usually either mixed with sugar or covered with syrup prior to freezing to hold these effects to a minimum.

Strawberries, raspberries, boysenberries, and loganberries are graded and washed according to size to prepare them for cold packing. They are then mixed with sugar as they are placed in 30- or 50-pound slip-cover tin cans or 50-gallon barrels, usually in the proportion of two parts of strawberries to one part of sugar, or of three parts of other berries to one part of sugar. They are then put in a sharp freezer, and in the case of barrels may be placed in a −10°F room provided with forced air circulation. After 48 hours here, they are generally stored at 10 to 15°F. Sliced berries, particularly strawberries, are mixed with sugar, usually in the proportion of 4:1, and run into bags standing in cold waxed cartons; the bags are heat-sealed, the cartons closed and overwrapped with heat-sealing transparent paper, and then placed in a Birdseye multiple freezer or other quick-freezing machine. Peaches are also sliced and covered with 60 per cent syrup to prevent browning, although recently mixtures of ascorbic and citric acid have been used successfully for treating sliced peaches to be quick-frozen.

The major problems, in the case of fruits, are those of the retention of color and flavor rather than texture. Packing with sugar and syrups tends to retard loss of these properties by displacing dissolved oxygen. If their natural juices do not readily dissolve the added sugar, heavy syrups are used to expedite such displacement, as in the case of 60 per cent sugar syrups for peaches. With such protection, the sweetened fruit is protected from extensive oxidation during cold or frigid storage.

Another type of problem is presented by the leakage of juices during the storage of frozen cherries. The freezing point of sucrose syrup is lowered by the invert sugars present in cherries. Moreover, the cherry is lower in pectin content than other fruits and its juice has a lower viscosity than strawberry juice, for example. Therefore, the juice remains more or less liquid even at 0°F, and ordinary packages of frozen cherries may leak badly in storage. For this reason, many packers do not pack frozen cherries for the retail trade, although according to Fitzgerald[4] the addition of a small amount of pectin could overcome this difficulty.

Many vegetables may be preserved better by freezing and cold storage than by any other method. However, all varieties do not freeze equally well. Since freezing softens plant tissues just as cooking does, freezing is equivalent to precooking; hence frozen vegetables require shorter cooking time than fresh. This softening effect may cause excessive leakage of juices in defrosting and cooking, as even the fastest commercial quick-freezing methods are not rapid enough to reduce leakage to any marked degree. If untreated vegetables are frozen and held in cold storage for more than a few days, their flavor and aroma will change because of the action of enzymes. Thus inactivation of the enzymes by blanching is necessary before freezing.

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[4] Fitzgerald, G. A., "ASRE Refrigerating Data Book," 4th ed., 1952.

Proper blanching of vegetables varies with the products themselves, although the time required depends principally upon the medium used, the temperature of the medium, the temperature of the product, the rate of circulation of the medium and the size of the vegetable or its sections. Apparently, conditions of time and temperature that bring the center of each vegetable, or each unit, to a temperature of 200°F or above will provide adequate blanching. Thus shelled peas need only about 60 seconds in boiling water or live steam, whereas large ears of sweet corn may require 8 to 10 minutes in the same medium to inactivate the enzymes of the kernels as well as those of the cob.

No attempt is made to inactivate all the enzymes present, as this might require complete cooking, with subsequent loss of color and flavor. It is the maximum retention of these that is the main purpose of freezing foods; otherwise, frozen foods have no advantage over canned foods. In order to retain the freshness, flavor, and vitamin content, it is not advisable to keep frozen vegetables at 0°F for longer than one year. Many operators recommend storage preferably below −5°F in order to guarantee keeping quality for a year. There is evidence of a continuous loss of vitamins in frozen vegetables stored at temperatures as low as −40°F, such losses becoming appreciable above −5°F. Tressler and Evers[5] have shown that there is a good correlation between retention of vitamin C in the storage and retention of flavor in frozen vegetables.

Generally, preparation of vegetables for freezing includes (1) selection of the proper variety and degree of maturity; (2) careful washing, cleaning and preparation for cooking; (3) sufficient blanching to inactivate the catalase content; (4) immediate cooling to 60°F or lower in cold water; (5) final inspection and filling of package; (6) quick-freezing, followed by storage at −5°F or lower. Considerable quantities of peas, snap beans and some other vegetables are frozen on meshed wire belts without previous packaging; this gives a free-flowing product which is then packed in suitable containers.

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[5] Tressler, D. K., and Evers, C. F., "Freezing Preservation of Foods," pp. 56–59, New York, Avi Publishing Co. Inc., 1947.

In general, vacuum-packed metal containers make the best package for frozen foods, as they prevent desiccation and minimize oxidation, the chief troubles which affect foods in frigid storage. While this form of packaging frozen foods is more expensive, it appears to be gaining favor among packers of certain fruits and some vegetables. The 30-pound enamel-lined tin has almost replaced the 450-pound barrel for industrial packs. The wet-waxed high-gloss carton is a passable package when over-wrapped with moisture-vapor proof film, or some similar protective wrapper. A frozen food package should contain at least one good vapor barrier. It is common practice to pack fruits-in-syrup in heat-sealable bags, usually coated parchment or high-wet strength paper. Some of the better films, such as polyethylene, give even better protection and their cost, while relatively high, appears to be lower as their use increases.

Freezing of Meats

Most of the frozen pork, beef, lamb and veal is fresh product. However, millions of pounds of pork and picnic hams are frozen and stored in sodium chloride brine. These products may be considered as being partly cured. Sometimes cured meats are packaged in moisture-vapor resistant paper or film, and frozen and stored according to the procedure for fresh meats. However, the frigid storage life of cured products is generally much shorter than that of fresh-frozen products, because of the greater susceptibility of cured meats to rancidity.

Freezing is accomplished at as low a temperature as possible, not only because the meat has a better appearance but because the capacity of the freezer rooms can be increased by expediting the turn-over of product. The ice-crystal pattern is determined by the rate at which meat is chilled to 25°F, although the temperature of the meat must be reduced to 0°F or lower for satisfactory storage results. If the temperature of the meat is quickly dropped through the zone of 31 to 25°F the ice crystals will be smaller than if its temperature is reduced slowly. At any given freezing temperature, there are a number of factors which increase the rate of freezing of meat: (1) methods which accelerate the transfer of heat; (2) packaging materials which have a low insulating value; (3) elimination of air pockets within the package; and (4) reduction of the thickness of the cut.

Carcass meat is frozen best when ample air space for circulation is provided around each, and when the carcass is encased in a stockinette. For example, heavy beef can be reduced to an internal temperature of 10°F in 24 to 36 hours in a blast tunnel at a temperature of −25 to −40°F, whereas 72 hours or longer may be required in a sharp freezer at 0 to −10°F with gravity coil refrigeration. Package meats are frequently frozen on shelf freezers. The freezing rate of meat can be progressively accelerated by increasing the velocity of the air from less than 50 fpm (natural air movement) to 200 fpm and to 500 fpm, although it does not seem to be materially influenced at higher velocities. Meats containing a high percentage of fat tissue freeze more quickly than those containing very little. On the other hand, beef, lamb, pork and veal freeze at similar rates when allowances are made for differences in the fat and moisture content; furthermore, aging and grinding beef do not significantly change its freezing rate.

Rapid air circulation expedites freezing, although care must be taken to prevent desiccation. For example, cut meat is usually packaged to prevent (1) surface desiccation or "freezer burn," (2) discoloration and loss of bloom, (3) shrinkage, (4) contamination, (5) chemical changes, and (6) freezing of the units into a mass if piled together. The quality of frozen meat is materially affected by storage conditions. It is important that the storage temperature be as low as economically feasible, as it has been demonstrated that storage temperatures of −10°F, −20°F and −30°F are progressively more effective than 0°F in retaining the quality of fresh meats. However, frozen meats prepared according to good commercial practice may be stored at 0°F for at least 3 to 4 months and retain their freshness. The relative humidity in the freezer storage rooms should be kept as high as is practical, and air circulation should be limited to that necessary to maintain a uniform temperature at all locations in the storage room. In some cases, air access in gravity coil freezers is minimized by piling the packages as tightly as possible after their initial freezing. Rapid air circulation—essential in some methods of freezing meats—must be avoided in frigid storage of meats.

Among the undesirable changes associated with poor meat-storage conditions are (1) development of rancidity in the surface fatty tissues; (2) desiccation of surface tissues, with consequent effect upon color, bloom, shrinkage and quality; (3) discoloration caused by ice crystal growth in surface tissues; (4) discoloration caused by oxidation of the myoglobin in surface tissues; and (5) deterioration by microbiological activity.

Probably the most important limiting factor in the storage life of meats is the stability of the fat. Pork fat is much less stable than beef fat; hence the storage life of pork is less than that of beef. The stability of the fat is characterized by an induction period, during the course of which oxidation proceeds slowly. Chemical methods of determining keeping quality of fats are usually based on the length of the induction period. The active oxygen method, for example, measures the amount of oxidation by the time required for a fat to reach a given peroxide level. The loss of moisture from the surface tissue of meats in freezer storage to a point where it contains only 10 or 15 per cent moisture is called "freezer burn," or desiccation. The red color of lean meat is due to the presence of a colored compound, myoglobin, in the muscle tissue. Myoglobin has a deep red color as it occurs in the unfrozen muscle. On exposure to air, a chemical reaction takes place between myoglobin (known also as reduced or unoxygenated myoglobin) and oxygen to form oxygenated myoglobin, which is bright red. Microbiological activity on the surface and within frozen meat ceases at 0°F and lower, whereas at high temperatures (above 14°F) yeasts and molds develop, causing deterioration in color, bloom and keeping quality.

In thawing frozen meats, the object is to reverse the physical changes that occurred during freezing and frigid storage. The degree of success obtained depends not only on the thawing procedure but to a great extent on the previous treatment of the meat. Defrosted meat should be firm, of good color, and not subject to drip or leakage. Beef is very susceptible to drip; veal and lamb are less so, and pork is the least susceptible of all. According to commercial practice, fresh-frozen meats are defrosted in humidified defrosting rooms at temperatures between 40 and 50°F and a relative humidity of 95 per cent. Quick-frozen meats are not subject to excessive leakage by rapid thawing if the temperature of the thawed meat is not allowed to go above 40 to 45°F.

Freezing of Poultry

With the aid of refrigeration, the poultry industry has grown into a large food-processing industry. In the last 15 years, a change has taken place in poultry production, involving emphasis on producing broilers for meat purposes. In 1934 broilers constituted only 3 per cent of all poultry produced; by 1940 this had increased to 14 per cent and by 1951 to 44 per cent. Poultry is grouped according to kind and class. The various classes of chickens include broilers, fryers, roasters, capons, stags, fowl and cocks. Based upon their dressed weight, broilers are young birds weighing under $2\frac{1}{2}$ pounds, fryers from $2\frac{1}{2}$ to $3\frac{1}{2}$, and roasters weigh over $3\frac{1}{2}$; the latter are sufficiently soft-meated to permit cooking by roasting. Stags are young male birds in state of maturity between roasters and cocks; capons are castrated male birds weighing over 4 pounds, while cocks are mature male birds. Fowl are matured female birds of any size. A differentiation in turkeys is made between young hens, old hens, young toms and old toms. Duck and geese are separated into young and mature birds, without reference to sex. The standards of quality for dressed and ready-to-cook poultry are based on conformation, fleshing, and fat covering, as well as on the degree of freedom from feathers, tears, cuts, disjointed or broken bones, discolorations and freezer burn.

There is a variety of ways of handling poultry from the time it is warm-dressed with its retained body heat to its final marketing. After poultry is dressed in accordance with present commercial methods the internal temperature is about 100°F. As the purpose of chilling the dressed poultry is to retard deterioration and to permit operators to place the stock in freezers or in trade channels the same day it is dressed, it is desirable to lower its temperature as rapidly as possible. Two principal methods of chilling are employed, one by direct contact with a cold liquid and the other by exposure to cold air. There are numerous variations in the methods of chilling, but, in general, air chilling leaves the skin rather dry whereas liquid chilling leaves it moist. Of the liquid chilling methods, the most common involves ice as the refrigerant, ice slush being very effective.

The purpose of freezing poultry is to maintain and preserve quality; hence the product should be placed in the freezer before deteriorative changes and bacterial growth have had a chance to impair quality. It was once common to use refrigerating rooms at about 15°F, but now much lower temperatures and air blast methods are used to freeze as quickly as possible. Poultry is generally frozen at air temperatures between 0 and −20°F, which are adequate for most types of packs. Temperatures lower than these are not desirable. Any method of freezing that permits the stock to have a natural bloom after being frozen is fully adequate from all quality considerations. Since freezing and proper storage temperatures check bacterial growth effectively, poultry should have relatively low bacterial counts when frozen. On being defrosted, it will deteriorate rapidly, for all the bacteria present are not destroyed during freezing and frigid storage. The danger that visceral taints will be imparted to the edible tissues in dressed poultry, if the product is frozen while in a strictly fresh condition, is negligible. Stewart, Hanson and Lowe[6] have reported that if dressed birds are brine-spray frozen within 5 hours after dressing, they can be held for 6 months in freezer storage before evisceration and remain superior even to birds adequately chilled and eviscerated 18 hours after dressing, and stored similarly. The main objective in handling dressed poultry intended for freezing should be to get it into the freezer and frozen before visceral taints or other deteriorative changes develop. It can then be kept in the freezer for a substantial storage period if the temperatures are sufficiently low and if the product is adequately protected from freezer burn.

It is generally believed that eviscerated poultry will deteriorate faster than dressed poultry. When bacterial counts alone are relied upon to indicate quality, drawn poultry should show more deterioration than dressed poultry, since considerable microbiological contamination occurs in removing the viscera. The product also is generally subjected to more washing with water than dressed poultry, and a wet surface favors bacterial growth and development. However, bacterial quality evaluations alone are not adequate, as they do not reflect the development of visceral odors and taints. When the latter are taken into consideration, it is just as reasonable to maintain that dressed poultry deteriorate more rapidly than drawn poultry. Post-mortem quality can be preserved and maintained in either dressed, drawn or eviscerated poultry when the product is properly handled.

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[6] Stewart, G. F., Hanson, H. L., and Lowe, B., *Food Research*, **8**, 202–11 (1943).

Under many circumstances, it can be maintained more easily when the poultry is drawn or eviscerated. However, the important consideration is that this operation alone does not insure that the product will preserve its original quality upon being promptly frozen and held at the proper storage temperatures. The growth of the eviscerated poultry industry has not been spectacular; in fact, it has been extremely slow, probably because operators in many instances have not understood how poultry should be handled prior to evisceration. Too often it was "old" before evisceration and freezing. Actually, poultry may be eviscerated either warm, after chilling, or even after freezing and defrosting. The warm evisceration of poultry, a relatively new method, appears to be most desirable, as there has been no opportunity for visceral taints to develop. Such poultry should be placed in a freezer soon after it has been eviscerated, or used promptly by the trade as unfrozen or ice-packed stock. In dealing with chilled dressed birds, it is desirable that the stock be eviscerated not later than the day following dressing, although the dressed birds can be held for longer periods (up to several days) before evisceration if special care is taken to hold them at 36°F or lower during the interim.

During storage, poultry may become dehydrated, which results in the condition known as freezer burn, which has been previously discussed. This can be avoided by humidification, lowering of storage temperatures, or by packing the product adequately. Aside from adversely affecting the appearance of the product, freezer burn, unless it is severe, does not impair quality. If storage temperatures of 0°F or lower are maintained, freezer burn is usually the factor limiting the time that poultry can be held in storage. Therefore, poultry should be carefully packaged in moisture-vapor proof packages and stored at 0°F or below if the storage period is to be of several months' duration. Furthermore, poultry fat becomes rancid during very long storage periods or if the storage temperatures are too high.

Freezing Fish

Fish are divided into two broad groups according to their flesh composition: (1) nonoily—those which store oil or fat in the liver such as cod, haddock, and pollock; (2) oily or fatty—those which store oil in the muscle tissue throughout the body, such as salmon, mackerel and herring. There are three primary causes of deterioration: (1) the action of bacteria which contaminate the seafood as a result of handling after removal from the water; (2) the oxidation of the oil or fat in the flesh; and (3) the action of enzymes contained within the tissues.

Generally, a period ranging from three or four days to several weeks elapses between the time fish are caught at sea and the time they are delivered to establishments. Even when the fish are packed in crushed ice as soon as possible after catching, considerable deterioration occurs before they can be marketed. For several years the industry has studied methods of overcoming the quality impairment attributable to the delay between catching and processing without arriving at an entirely satisfactory solution. Freezing fish at sea is not new: it has been practiced by the Dahl process of spraying brine over fish packed in wooden boxes ready for market. Complete processing has been attempted on shipboard, and during recent years several fishing vessels have been equipped with either blast or sharp freezers.

Fillets cut from fish immediately after catching, packaged and frozen on board are far superior in flavor, appearance and texture to those handled by other methods. These operations have not been entirely satisfactory because of the difficulty of removing fillets at sea due to the movement of the ship. Filleting is now done almost entirely at shore plants. More recently fish have been frozen in the round in freezers aboard ship. They are then glazed and stored in the hold at a temperature of 0 to −10°F, and so held until landed; then they are defrosted only sufficiently for filleting. As soon as the fillets are cut and packaged, they are refrozen. Such fillets have superior flavor, texture and slightly less drip than those cut from fish which have been packed in ice for a week or more before filleting. These characteristics are further emphasized upon long freezer storage.

Fish are frozen by a great variety of quick-freezing methods now available. These methods are too numerous to discuss individually, although they may be classified as follows: (1) sharp freezer, (2) air-blast freezer, (3) refrigerated metal contact freezer, and (4) brine-spray freezer. The first to be adopted was the sharp freezer method, whereby the fish are placed in a room kept at as low a temperature as possible and left there until frozen. This technique has been improved on by the use of air-blast or air-circulating systems to expedite the rate of freezing: some types of freezers use "Dry Ice" as a refrigerant, instead of conventional brine or ammonia coils. Another type operates by bringing the fish into contact with a refrigerated metal surface, such as a plate or pan. In some cases, the pans are in contact with the liquid brine refrigerant, thus providing the heat-transfer surface; in other cases the fish, usually packaged, are placed between two plates chilled by direct expansion ammonia or by brine-circulating coils. The brine spray or fog systems, as the name indicates, force a fine spray of chilled brine onto the fish until they are frozen, after which they are packaged. There are, of course, many variations in the method of arranging the spray nozzles and in handling of the fish to be frozen; some freezers of this type are constructed so as to operate continuously.

All species of shell fish may be frozen by any one of the varieties of quick-freezing methods now in use. Shrimp, the most common shellfish found in cold storage, are frozen both before and after cooking, the bulk of the pack being raw. The usual procedure is to remove the heads, then wash the shrimp and pack them in rectangular 5- and 10-pound cartons, which are placed on the coils in a sharp freezer. After freezing, the shrimp are usually glazed by dipping the frozen mass into cold water, which fills the air holes and freezes to give the glazed appearance. Cooked shrimp can be stored for only a short time before losing considerable flavor and texture.

Oysters are shucked, washed thoroughly with dilute brine, graded for size and then packed, usually in moistureproof, cellophane-lined, rectangular cartons, and frozen in multiplate freezers or on shelf freezers. Clams and scallops are handled and frozen in the same way; crabs and lobsters are usually cooked in steam retorts and cooled before the meat is separated for packaging and freezing.

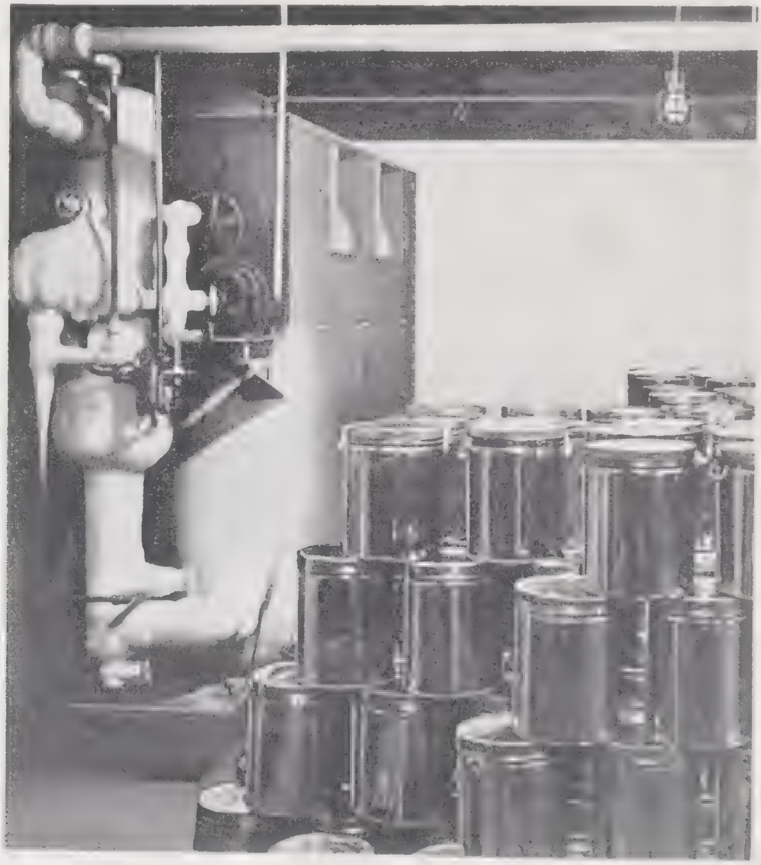
Fish and shellfish are usually held in freezer storage at 0 to −10°F. As constant a storage temperature as possible is important in frigid storage of fish products, for when the glazed surfaces are evaporated, freezer burn will take place rapidly. Usually, public warehouses store fish in special cold storage rooms, as the odor gradually gets into the walls and is difficult to eliminate.

Types of Heat Exchangers

Sharp freezers have been employed most widely in the freezing of foods, although their use is decreasing rapidly. A sharp freezer (or slow freezer) is essentially a very cold room or cabinet capable of maintaining temperatures varying from approximately 10 to −20°F or lower. The products to be frozen are placed in it until they reach a corresponding temperature and become solidified or hardened by freezing. The air within a sharp freezer circulates by natural convection currents due to the extraction of heat from the products being frozen, and usually no provisions are taken to increase this rate. The relatively still air is a poor conductor of heat, and food placed even in sharp freezers at very low temperatures freezes rather slowly.

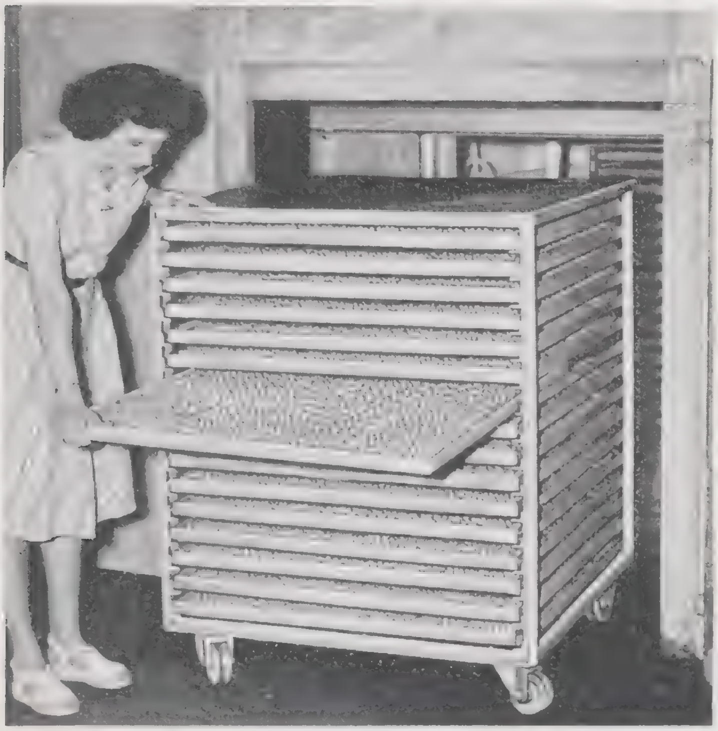
Many hours or even days may be required before foods are completely frozen, depending, of course, upon their bulk, packaging and stacking. Therefore, the term "slow freezing" has been generally applied to sharp freezer practice. While sharp freezers are obviously not as desirable for freezing most foods as are other types, they have considerable utility for frigid storage. Generally, air circulation is kept at a minimum in the cold storage of most frozen foods, to prevent desiccation.

Air-blast freezers are widely used to produce a great variety of quick-frozen foods of excellent quality. These freezers differ markedly from sharp freezers in that they are usually designed in the form of tunnels, and take full advantage of the heat-transfer effectiveness of rapidly circulating air. Very cold air in rapid motion may be provided by directing high-velocity air currents through the refrigerated coils in a sharp freezer, for example. (see Fig. 23.11). However, if even more rapid freezing is desired, the cold air blast may be confined to an insulated tunnel and directed past the surfaces of the product from which heat is being extracted. Temperatures used in air-blast freezing range from 0 to −30°F, although even lower temperatures are sometimes used. Air velocities of from 100 to 3500 fpm have been reported, although in most cases velocities much in excess of 1000 fpm appear to be of questionable advantage. Tunnel freezing of unpackaged foods has



Courtesy Frick Co.

FIG. 23.11. Air-blast freezer for freezing broken eggs.

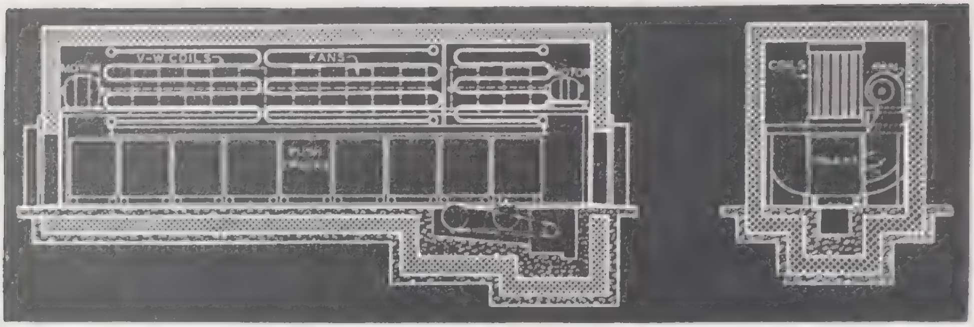


Courtesy Frick Co.

FIG. 23.12. Freezing peas on tray truck in air-blast freezer.

two inherent disadvantages, namely: (1) the attendant dehydration of the food being frozen; and (2) since the refrigerated air is recirculated to minimize the cost of lowering or maintaining its temperature, there is need for constant defrosting of the equipment due to moisture given off by the food being frozen (see Fig. 23.12).

One type of air-blast freezer consists of a well insulated cabinet with cooling coils in bunker at the top and tray trucks or conveyor belts below. Cold air passes rapidly over the food and back through the cooling coils. Special cooling coils have been developed for this system and it is claimed that temperatures as low as −80°F can be maintained (see Fig. 23.13). Another type is in the form of a vertical freezer in which trays of product are moved upward through an air blast. A timing device controls the movement of the trays and is set for a predetermined freezing cycle to meet the needs of the product, depending on whether it is loose-frozen or package-frozen. For loose-frozen products, such as peas, beans, cut corn and other vegetables, filled trays are fed in at the bottom of the freezing column; each tray is stepped upward at a predetermined rate and discharged at the top by automatically dumping the frozen product and returning the empty tray to the starting position. At the top of the freezer, the product passes from the dump hopper through a breaker to disaggregate any large clusters



Courtesy Frick Co.

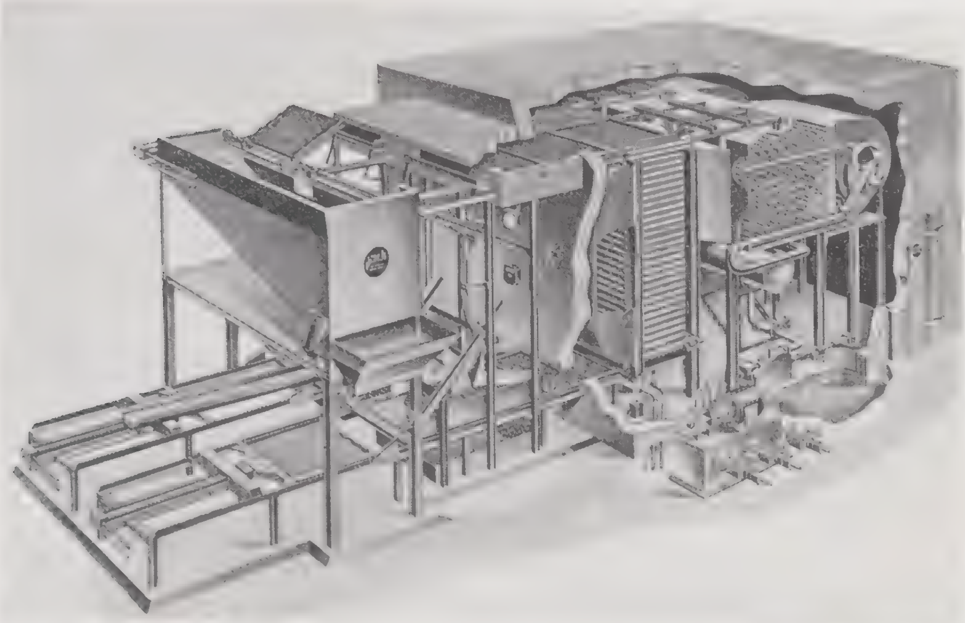
Fig. 23.13. Side and end view of a track-tunnel for freezing foods in frigid air blast. Note conveyor for pushing trucks.

and is then fed by gravity or conveyor to the packaging machine. The operation is similar when packaged foods are frozen, except that the packages are placed on the trays by hand and removed upon being discharged from the machine (see Fig. 23.14).

Indirect-contact freezers are devices that freeze food products by engaging the product with a metal surface cooled by freezing brine or other heat-extracting media. In principle, it is similar to the old-fashioned method of freezing ice cream in a can immersed in a mixture of ice and salt, the heat of the ice-cream mixture being extracted through the metal side wall and ends of the container. There are many types of such freezers, such as those used for packaged foods, where the refrigerating coils are used as shelves on which to place the packages until their contents are frozen. We have already referred to the pan method of freezing fish where the food is placed in a pan that is either floated on refrigerating brine or placed on the refrigerating coils, as just mentioned.

Birdseye (1926) built a double-belt quick-freezing apparatus which consisted of two endless stainless steel belts, one above the other, running through a freezing tunnel at the same speed and in the same direction. The refrigerant used was calcium chloride brine at a temperature of about −50°F; this was sprayed against the under side of the lower belt and against the top side of the upper belt. As the upper belt was wider than the lower, the brine cascaded over the sides of the lower belt without touching the product being frozen between the two belts. This machine is now obsolete and all the original freezers have been dismantled.

Later Birdseye and Hall originated the multi-plate freezer which, as the name implies, consisted of a number of superimposed refrigerated hollow plates actuated by means of hydraulic pressure so that they could be opened to receive products between them and then closed on the product with any desired pressure. Ammonia or brine was circulated as the refrigerant moved through the hollow passages of the plates. For the continuous freez-



Courtesy York Corp.

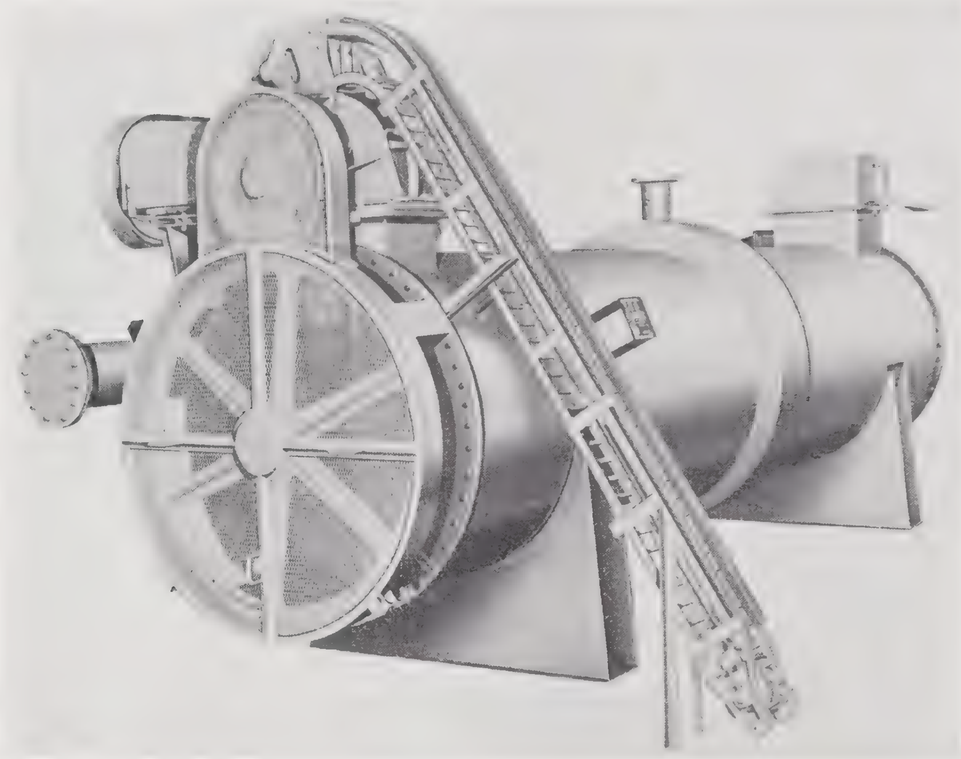
FIG. 23.14. Vertical air-blast freezer which automatically freezes peas, beans and other vegetables.

ing of small vegetables and fruits, and liquids such as cream, Birdseye (1940) developed the *gravity froster*. The product to be frozen is continuously fed by controlled amounts into the top of the freezer through a vibratory feed hopper or measuring valve. As the food falls onto the receiving end of the top plate it is moved along the surface of the plate by scrapers until it falls by gravity from the other end. This process continues from plate to plate until the frozen product drops out of the outlet at the base of the freezer. Scrapers on the underside of the plates remove the condensed moisture. This entirely automatic operation rapidly freezes foods, and the machine has a large capacity in relation to its size and cost.

We have already discussed the Finnegan tubular freezer used extensively for freezing full strength fruit juices (see Fig. 23.5).

D. G. Sorber (1933) patented a method by which food products packaged in hermetically sealed tin cans are frozen by immersion in an apparatus that is essentially the same as a continuous cooker, except that materials are modified to withstand low temperatures and the effects of the refrigerant, which has an ethyl alcohol base. The refrigerant is made to flow in a direction opposite to that of the cans being processed.

A very interesting indirect contact freezer is the FMC 55″ round shell continuous freezer originally designed to freeze canned citrus concentrates and similar liquids filled in 202 × 214, 202 × 208 and 202 × 314 cans at



Courtesy Food Machinery and Chemical Corp.
FIG. 23.15. Continuous round shell direct immersion freezer.

speeds up to 300 cans per minute (see Fig. 24.15). Similar freezers are available for larger can sizes. Recently this unit was given wider application in freezing strawberries and peas, with every indication that other fruits and vegetables will be similarly frozen.

The construction is similar to that of the FMC continuous cookers and coolers with the exception that the inner reel of the freezer is sealed. The cans travel between this sealed reel and the outer shell. The brine refrigerant is pumped at a rate of 800 gpm through a manifold located around the center of the machine and the flows at high velocity toward each end of the freezer. This confined, high-velocity brine circulation greatly increases the rate of heat transfer and thus lessens the freezing time. Cans are at all times completely submerged in the brine. The freezer is equipped with a right-hand positive feed elevator, which raises and feeds the cans into the feed turret, located on the top center line of the freezer, which in turn moves the cans into the machine. An extractor type discharge gently removes the cans from the freezer. In addition to the high can speeds possible, another important advantage of this machine is the fine crystal formation in the frozen product. Due to the can motion during freezing, a completely homogeneous, fine-grained product is obtained, even when cans are filled with product directly from the evaporators or cold-wall holding tanks, without any other prefreezing operations.

Direct-immersion freezers are those which freeze foods by directly immersing them in low-temperature refrigerants. Actually, quick-freezing was probably initiated with the application of low-temperature brine in the freezing of fish. As liquids are good conductors of heat, products may be frozen rapidly by direct immersion in low temperature liquids such as sodium chloride or sugar solutions. Fundamentally, direct-immersion freezers provide either the means for pumping a continuous stream of the refrigerant past or over the products to be frozen and in direct contact with them, or, to reverse the process, the means for mechanically conveying the product through the refrigerant solution. Obviously, the refrigerating media must be edible, to be suitable for the direct immersion of foods, and must remain unfrozen at 0°F and below.

Two of the most important advantages of direct-immersion freezing are: (1) intimate contact between refrigerant and product, with a very high rate of heat transfer; and (2) the fact that the resulting product is not a solidly frozen block, since each article is a separate unit. On the other hand, there are several disadvantages such as: (1) penetration of the refrigerant into the tissues of the product, causing undesirable changes; (2) extraction of juices from the foods by the process of osmosis, thereby contaminating and diluting the refrigerant; and (3) difficulty in keeping the refrigerant free from dirt and other contaminating influences.

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